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AF-GEOSPACE USER'S MANUAL VERSION 2.5.1 AND VERSION 2.5.1P

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Technical Report

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14. ABSTRACT

AF-GEOSpace is a user-friendly, graphics-intensive software program combining space environment models, applications, and data visualization products developed by the Air Force Research Laboratory and the space weather community. Models of the radiation belts, South Atlantic Anomaly, aurora, magnetospheric plasma and fields, magnetopause, ionosphere, neutral atmosphere, meteor impacts, interplanetary shock propagation, cosmic rays, solar energetic particles, and geomagnetic cutoff rigidity are included. Applications address radiation dose, linear energy transport, ionospheric scintillation and HF-ray propagation, and magnetic fieldline tracing. Data modules display DMSP particle spectra, user-provided satellite data and ephemerides, and 3D gridded simulation data sets. AF-GEOSpace enables operational product prototyping, model validation, environment specification for spacecraft design, mission planning, frequency management for HF communications, and satellite anomaly resolution. Graphical tools include stations, radar fans, satellites, links, detector cones, coordinate probes and slices, isosurfaces, orbit data probes, grids, and magnetic field-lines. For comparison, use of common input parameter sets supports the creation of animations displaying output from multiple space environment models for a given time interval.

15. SUBJECT TERMS

Space environment hazards, Visualization, Radiation Belts, Electron, Proton, Dose, Ionosphere, Scintillation, HF Ray Tracing, Orbit Propagation, Plasma Sheet, Interplanetary Shock, Geomagnetic Field, Aurora, Neutral Atmosphere, Meteor Impacts, Cutoff Rigidity

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WELCOME TO AF-GEOSPACE VERSIONS 2.5.1 AND 2.5.1P

AF-GEOSpace is a user-friendly, graphics-intensive master program bringing together many of the space environment models and applications developed over the years by the Air Force Research Laboratory, its contractors, and collaborators. The program has grown steadily in an effort to address the concerns of the space weather community, to assist in providing an historical validation baseline for relating models covering similar domains, and to act as a development tool for automated space weather visualization products. It provides common input data sets, application modules, and 1-D, 2-D, and 3-D visualization tools to all of its models. AF-GEOSpace provides operators, engineers, forecasters, scientists, students, and teachers with tools to accomplish a wide variety of tasks, for example:

- Optimal orbit specification for avoidance of radiation hazards
- Satellite design assessment and post-event anomaly analysis
- Forecasting of solar disturbance effects
- Frequency and antenna management for radar and HF communications
- Determination of communication link outage regions for active ionospheric conditions
- Specification of meteor flux rates along orbits plus probabilities of incurring damage
- Display of user-formatted space environment sensor data with orbit trajectories
- Display of user-generated 3-D gridded simulation results for model comparison
- Display of DMSP particle spectra and integrated flux from the SSJ4/5 particle sensors
- Display tools for interpreting MHD simulation results on large-scale structured grids
- Determination of location of geomagnetic footprints of satellites for conjunction studies
- Determination of spacecraft distance from the magnetopause boundary layer
- Specification of overall atmosphere, ionosphere, aurora, plasmasphere, radiation belt, and magnetosphere particle populations
- General interplanetary, magnetospheric, and ionospheric physics research and education

A review of the software development history reveals a strong emphasis on retaining and enhancing the capabilities of earlier releases.

Development Overview

The first public release of AF-GEOSpace was Version 1.21 (1996; IRIX on SGI) contained radiation belt particle flux and dose models derived from CRRES satellite data, an aurora model, an ionospheric model and HF ray tracing capabilities. Version 1.4, (1999; IRIX on SGI) added science modules related to the cosmic ray and solar proton environment, low-Earth orbit radiation dosages, single event effects probability maps, and ionospheric scintillation, solar proton, and shock propagation models. New application modules for estimating linear energy transfer (LET) and single event upset (SEU) rates in solid-state devices, and modules for visualizing radar fans, communication domes, and satellite detector cones and links were added.

Automated FTP scripts permitted users to automatically update their global input parameter data set directly from the NOAA National Geophysical Data Center (NGDC).

AF-GEOSpace Version 2.0 (2002; Windows) included the first true dynamic run capabilities and offered new and enhanced graphical and data visualization tools such as 3-D volume rendering and eclipse umbra and penumbra determination. The dynamic run capability enabled the animation of all model results, in all dimensions, as a function of time. Version 2.0 also included a new realistic day-to-day ionospheric scintillation simulation generator [IONSCINT], an upgrade to the WideBand Model scintillation code [WBMOD], a simplified HF ionospheric ray tracing module [RAYTRACE-APP], and applications built on the NASA AE-8 and AP-8 radiation belt models [NASAELE-APP and NASAPRO-APP]. In addition, user-generated satellite data sets could be visualized along with their orbital ephemerides [EPHEMERIS] and a tool was provided for visualizing MHD model results stored in structured grids [PARAMESH].

AF-GEOSpace V2.1 (2006; Windows) followed with new capabilities: (1) to trace geomagnetic field-lines from user-specified points or points along a satellite orbital track [BFOOTPRINT-APP], (2) calculate cutoff rigidity values for solar protons and cosmic rays for any altitude from within the Earth's atmosphere to beyond geosynchronous orbit [CUTOFF], (3) display particle energy spectra and integrated precipitating flux from the DMSP SSJ4/5 sensors [DMSP], (4) calculate hourly meteor impact or damage rates for a given cross section, pit depth, and material type on a user-specified surface area at positions outside of the Earth's atmosphere [METEOR IMPACT MAP], (5) estimate meteor flux or damage rates as well as cumulative probabilities for a user-specified surface as a function of time along an orbit path [METEOR IMPACT-APP], (6) estimate the number of meteors visible from ground-level resulting from active meteor showers (or user-specified storms) [METEOR SKY MAP], (7) generate time-dependent flux profiles of electron, H^+, and O^+ particle fluxes in the inner and middle magnetosphere [MSM], (8) compute atmospheric number densities, total mass density and temperature as well as anomalous oxygen number density and exospheric temperature [NRLMSISE-00], (9) model the solar-cycle dependent low-altitude extension of the proton radiation belt [TPM-1], and (10) calculate omni-directional proton fluence (integral and differential) along user-specified orbits [TPM-1-APP].

What's New?

AF-GEOSpace Version 2.5.1, containing the same set of software modules as Version 2.5 (2010; Windows), has undergone extensive additional testing and debugging to ensure compatibility with the Windows 7 operating system. As such, this user's manual contains only minor editorial revisions when compared to that of Version 2.5. Version 2.5 expanded on the content of Version 2.1 by including new modules and updates related to the following topics: (1) energetic proton maps for the South Atlantic Anomaly for the epoch 2000-2006 [SAAMAPS-2007], (2) GPS scintillation outage simulation tools [IONSCINT-G, IONSCINT-G-APP, plus the related IONSCINT-G graphics module], (3) magnetopause boundary location determination [MAGNETOPAUSE], (4) a 2008 empirical description of thermal plasma densities in the plasmasphere, plasmapause, magnetospheric trough, and polar cap [GCPM], (5) the International Reference Ionosphere model [IRI-2007], (6) a new inner magnetosphere plasma population model [CAMMICE], (7) new dynamic magnetic field models driven by archived input coefficients valid back to 1963 [BFIELD-APP and BFOOTPRINT-APP], (8) the ability to display externally-produced 3D gridded data sets [GRID], (9) a 2005 update to the geomagnetic cutoff rigidity model [CUTOFF], (10) a 2005 update to the ionospheric scintillation Wide-Band Model [WBMOD], (11) improved magnetic field flux mapping options for the existing set of

AF-GEOSpace radiation belt models [APEXRAD, CRRESELE, CRRESPRO, CRESSRAD and TPM-1], and (11) the capability to display the latest DMSP data sets [DMSP].

Code Architecture

AF-GEOSpace Version 2.5.1 is an object-oriented code written in C++ for Windows (XP, Vista, and 7). It is rigorously object oriented and contains separate user interface, kernel, and graphics libraries. The software is divided into five explicit module classes to simplify the integration of new algorithms and increase portability. *Science Modules* control individual science models and produce output data sets on user-specified grids. *Application Modules* typically manipulate these data sets, e.g., by integrating dose calculated by a radiation belt model or tracing HF rays through a model ionosphere. Application modules also provide orbit generation and magnetic field line tracing capabilities. *Data Modules* read and assist with the analysis of user-generated and DMSP data sets. *Graphics Modules* control the one, two, and three-dimensional windows and enable display features such as plane slices, magnetic field lines, line plots, axes, the Earth, stars, and satellites. *Worksheet Modules* provide commonly requested coordinate transformations and a calendar system conversion tools.

Comments

Perhaps the most important parts of this document are found at the end in the *EXAMPLES* section. There you will find click-by-click instructions for using AF-GEOSpace to investigate solar, magnetospheric, and ionospheric phenomena that have well known effects on communications and spacecraft systems. Examples exercising the dynamic run feature of AF-GEOSpace are marked as such in the title.

AF-GEOSpace software is distributed exclusively by the Space Weather Center of Excellence within the Space Vehicles Directorate of AFRL. The AF-GEOSpace development team appreciates comments, bug reports, and content suggestions for future software. Contact information is in the *PRODUCT INFORMATION* section at the end of this document.

Release Notes on the User's Manual and Software

The AF-GEOSpace User's Manual, Version 2.5.1 and Version 2.5.1P (this document), approved for unlimited public distribution, describes two AF-GEOSpace software application packages released concurrently by the Air Force Research Laboratory (AFRL). AF-GEOSpace software was developed by the US Air Force and cannot be redistributed or copied in whole or in part for sale. The USAF and the Air Force Research Laboratory are not liable for any damages resulting from the use of the information contained in this document or the computer software it describes.

Version 2.5.1 software (DVD), distributed by AFRL to pre-approved government institutions and their agents, includes the complete inventory of Science and Application Modules listed in the table of contents of this User's Manual. Members of the general public who wish to obtain this version of the software should contact the AF-GEOSpace development team to initiate the necessary release approval procedure.

Version 2.5.1P software (CD), approved for unlimited public distribution, is identical to the Version 2.5.1 software except for the absence of seven Science Modules (i.e., IONSCINT, ISPM, MSM, PPS, STOA, TPM-1, and WBMOD) and two Application Module (i.e., TPM-APP and WBPROD-APP) marked "V2.5.1 Only" in the table of contents. If interested in obtaining the modules excluded from Version 2.5.1P, please contact the AF-GEOSpace development team.

Automated Installation of AF-GEOSpace

(1) Insert the AF-GEOSpace Software Media
If the *Install* window does not appear, then run the *setup.exe* program directly. [If the setup popup window does not appear or you are requested to provide an administrative user name/password but do not have administrative privileges, then please follow the *Manual Installation* instructions detailed in the next section.]

(2) Set the Install Directory
A new directory named "AFGeospace" will be created in the selected Install Directory. **The Install Directory path name can have a maximum of 35 characters**. All executable and data files will be copied into the Install Directory. **Note**: All future references made in this document to the "AFGeospace" directory path will use the name "$AFGS_HOME".

(3) Set the Scratch Directory
When AF-GEOSpace runs each model creates a directory where temporary data needed to run the model is stored. When the model is deleted, or AF-GEOSpace exits, these directories are deleted. The Scratch Directory path tells AF-GEOSpace where to create these directories.

(4) Select links to be created (to Start Menu and/or Desktop)
Links to run AF-GEOSpace can be automatically placed in the *Start >Programs* menu and on the windows Desktop. Place a check in the *Add to Start Menu* and/or *Make Desktop Shortcut* boxes to create the links. Note: AF-GEOSpace will need to be installed with write permission to the *Start* menu directory structure for the links to be successfully created.

(5) Install AF-GEOSpace
Click the *Install* button to begin the actual installation. The *Install* window will show installation progress and issue a completion message. The *Cancel* button will interrupt installation.

Option for Version 2.5.1: If the MSM Science Module is required, copy the DVD directories *TLBMAT* and *BMATRIX* (1.5 GB total) into the directory $AFGS_HOME\models\data\MSM.

Manual Installation of AF-GEOSpace

(1) Insert the AF-GEOSpace Software Media

(2) Create the Install Directory

Create a new directory called "AFGeospace" for use as the installation location. The path name of the directory where "AFGeospace" is placed can have a maximum of 35 characters. Copy the *bin* and *models* directories from the media and place them in the new directory *AFGeospace*. Note that all future references made in this document to the "AFGeospace" directory path will use the name "$AFGS_HOME".

(3) Edit the Batch Files for Running AF-GEOSpace and Updating Global Inputs

Copy the files named *AFGeospace.bat* and *AFGetSec.bat* and place them in the newly created machine directory $AFGS_HOME\bin. Each file contains a set of commands to set machine environment variables followed by a call to an executable file, namely

File AFGeospace.bat:

```
1) set PLGS_MODELS=C:\Users\username\AFGeospace
2) set PLGS_SCRATCH_DIRECTORY=C:\TEMP
3) set PLGS_DMSP_DATADIR=C:\Users\username\AFGeospace\models\data\DMSP\2003
4) "C:\Users\username\AFGeospace\bin\AFGeospace.exe"
```

File AFGetSec.bat:

```
1) set PLGS_MODELS=C:\Users\username\AFGeospace
2) set PLGS_SCRATCH_DIRECTORY=C:\TEMP
3) "C:\Users\username\AFGeospace\bin\AFGetSec.exe"
```

Initially, fictitious paths are set for the location of the *bin* and *models* directories, i.e., $AFGS_HOME = C:\Users\username\AFGeospace in the sample file content shown above. Edit both files to reflect your install location, i.e., replace the character string "C:\Users\username" in each of lines 1, 3, and 4 of file *AFGeospace.bat* and also in lines 1 and 3 of file *AFGetSec.bat* with a character string designating the actual location of directory *AFGEOSpace*.

(4) Confirm Location of the Scratch Directory

As AF-GEOSpace runs, each new module creates a directory where temporary data needed to run the model is stored. The default location of the scratch directory as noted in both batch files is `C:\TEMP`. If this directory does not currently exist on your machine, then either create one or edit line 2 of both batch files to specify the location of an existing directory to be utilized for scratch space. Note that when the model is deleted, or AF-GEOSpace exits, the temporary data directories are deleted.

(5) Create a Desktop Shortcut

Right-click on the newly edited file $AFGS_HOME\bin*AFGeospace.bat* and select *Create Shortcut*. Place the shortcut on your Desktop or elsewhere for convenient access to the software.

(6) Option for Version 2.5.1: If the MSM Science Module is required, copy the DVD directories *TLBMAT* and *BMATRIX* (1.5 GB total) into the directory $AFGS_HOME\models\data\MSM.

Running AF-GEOSpace

To run AF-GEOSpace, double-click on the AF-GEOSpace Desktop icon or use the Start menu (*Start > Programs >AFGeospace > AFGeospace*). If no links were created during installation, start AF-GEOSpace by going to the $AFGS_HOME\bin directory and double-clicking on the *AFGeospace.bat* file. Be aware that the file *AFGeospace.bat* contains Environment Variable settings specific to the Install and Scratch directories you selected during the installation process. For this reason, if you would like to change the location of any part of the installation it is best to first remove AF-GEOSpace completely (see *Removing AF-GEOSpace* below) and then re-install it to properly designate the preferred Install and Scratch directory locations.

Note: AF-GEOSpace will not work properly if you run the *AFGeoSpace.exe* file directly.

Three windows will appear on your screen. One is the AF-GEOSpace graphical user interface (GUI) with a set of pull-down menu items across the top. The other two are shell windows (plain text windows, usually with black backgrounds). You can minimize these to clean the desktop, but **the shell windows must remain open for AF-GEOSpace to function**. To optimize the quality of the display layout and increase ease of use, it is best to maximize the AF-GEOSpace GUI window immediately upon starting a session.

When large fonts are used in your display, the text in the GUI Environment Window may appear to overlap or be crowded. If this occurs, adjusting your display to use small fonts should clean up your AF-GEOSpace display layout.

At the end of this document, some AF-GEOSpace examples are provided with detailed step-by-step instructions to help the user visualize results from both static and dynamic model runs.

An electronic copy of this document can be found in $AFGS_HOME\models\HELP.

Removing AF-GEOSpace

To remove AF-GEOSpace, delete the $AFGS_HOME directory. If a desktop icon was created then place it in the recycle bin. If a link in the *Start* menu was created, remove the *AFGeospace* submenu item by following the *Start* Menu handling instructions available using *Start > Help*. Because the installation does not modify the machine registry, removal is complete at this point.

A Note on Virtual Memory

If users find the machine running out of virtual memory, the virtual memory paging file size can be adjusted by following the instructions found using Windows Help.

ENVIRONMENTS

Environment modules provide interfaces to the science models and related applications needed to investigate the solar, interplanetary, magnetospheric, auroral, and ionospheric environments and their effects on communications and spacecraft systems. AF-GEOSpace Version 2.5.1 supports two basic environment module types: *static* and *dynamic*. Modules that do not operate in *dynamic* mode are marked as "Static Only" in the table of contents of this manual.

Upon opening AF-GEOSpace, an Environment Window is displayed containing a menu bar and an input section for specifying the module run times and global parameters used to drive models during the session. When using AF-GEOSpace to do comparative studies of space environments for different geophysical conditions it is recommended that a new AF-GEOSpace session be used for each case, i.e., for each time or time period. Remember that the models contained in AF-GEOSpace were developed independently over a period of many years by a variety of authors.

Static versus Dynamic Mode

Static Mode: A Science or Application module run is called *static* if it produces output representing a single Universal Time, i.e., only the *Start: Year*, *Day*, and *UT* text fields are completed in the global input row at the top of the Environment Window. All environment models and applications are run using a fixed set of geophysical parameters, e.g., the geomagnetic activity index *Kp*. With the exception of the MSM Science Module and the satellite orbit generator SATEL-APP and associated applications (APEXRAD-APP, BFOOTPRINT-APP, CRRESELE-APP, CRRESPRO-APP, CRRESRAD-APP, LET-APP, METEOR IMPACT-APP, NASAELE-APP, NASAPRO-APP, TPM-APP) all environment models and applications can be run for a fixed Universal Time.

Dynamic Mode: A Science or Application module run is called *dynamic* if it produces output at more than one Universal Time, i.e., both the *Start:* and *End: Year*, *Day*, and *UT* text fields are completed in the global input row at the top of the Environment Window. It must be emphasized that most *dynamic* module runs are composed of a time-ordered sequence of *static* runs. A *dynamic* mode run is established by placing a check mark in the small box to the right of the *Start: UT* text field to activate the *End: Year*, *Day*, and *UT* text fields. Selecting one of the *Globals* options to the right of the time input text fields will create a chronological list of global input parameters that module runs will share during the session. This common set of global input parameters allows you to automatically run models in a coordinated manner so that output displays of varying types of generated physical parameters, e.g., auroral precipitation patterns and geomagnetic field lines, will be consistent with each other to the greatest extent possible without truly coupling the models. Again, the SATEL-APP orbit generation module and related applications work in both *static* and *dynamic* mode. When SATEL-APP is opened in *static* mode, the satellite orbit will be calculated for the 1-day interval beginning with the *Start* time. However, when SATEL-APP is opened in *dynamic* mode the satellite orbit will automatically be calculated for the entire time period defined by the entered *Start/End* time limits.

Global Parameters

Global parameters are the date, time, and geophysical indices shared between many of the models. The purpose of the global parameters section is to help maintain consistent inputs to the plurality of models that can be created within a single static or dynamic environment. Most models have additional parameter inputs that will be requested when initializing the appropriate module.

IMPORTANT NOTE: THE FIRST THING A USER MUST DO AFTER OPENING AN AF-GEOSPACE APPLICATION IS SET THE TIME AND OBTAIN THE GLOBAL INPUT PARAMETERS. The following time and global parameter input controls are located in a row just below the pull-down menus at the top of the window:

Start: (three items are set for both static and dynamic runs)

- **Year**: Start Year
- **Day**: Start Julian day of year in the form DDD
- **UT**: Start Universal Time in the form HH:MM

"Box": To set up a dynamic run, place a check mark in the box next to the *Start: UT* text field and the following three end time text fields will become active.

End: (three items are set for dynamic runs only)

- **Year**: End Year
- **Day**: End Julian day of year in the form DDD
- **UT**: End Universal Time in the form HH:MM

Kp: Planetary magnetic activity index input in decimal form

SSN: Daily sunspot number

F10.7: Instantaneous solar radio flux at 10.7 cm (2800 MHz) in $10^{-22} Wm^{-2} Hz^{-1}$

Ap: Planetary magnetic index in integer form

Kp, SSN, F10.7, and Ap are provided for 1932 through April 2012 and their definitions are identical to those used for the geophysical index archives maintained by the National Geophysical Data Center (NGDC) in Boulder, Colorado.

After the time text fields are adjusted, the user must use the *Global* selector (options are *Archive*, *Prelim*, or *Latest* as described below) to retrieve the global inputs and initialize AF-GEOSpace with the run time. The geophysical indices are flagged with the unphysical values of "-1" if data are not available for the selected time or interval. Values for these flagged parameters or any of the parameters can then be directly edited using the text boxes. As described in the Menu section, the input parameters extracted from the data files can be adjusted for dynamic runs using the *Globals:Show* pulldown menu. Editing the parameters directly before running a module allows the user to run the entered time or interval using parameters not contained in the global data sets. Additional parameters accessible via the *Globals:Show* pulldown menu are,

Dst: Geomagnetic activity index in *nT* (1957 through May 2012)

EqE: Equatorward boundary of the diffuse aurora at midnight in units of degrees magnetic latitude (1983 through Day 83 of 2010)

Note that most modules will provide a summary of times run and input parameters used in the *Model Status* box at the bottom of the Environment Window.

The global parameter values can be plotted in a 1D viewport window using the *Global Inputs* graphical module. The last two parameters are included for reference purposes. The *Dst* parameter is useful when constructing magnetic field models using the BFIELD-APP application and the *EqE* values are useful as manual input to the AURORA science module equatorward edge-mapping algorithm.

These options for the global parameters files are given below.

Archive

When *Globals:Archive* is selected, the NGDC archived values of the geomagnetic indices valid for the *Year, Day*, and *Time* entered in the respective global parameter boxes are automatically loaded. AF-GEOSpace Version 2.5.1 contains the NGDC geophysical index archive files in the directories:

$AFGS_HOME\models\data\GLOBALS\KP (contains indices Kp, SSN, F10.7, and Ap)

$AFGS_HOME\models\data\GLOBALS\DST (contains the Dst magnetic index)

Each file in these directories contains a year's worth of indices with the current year's file only partially full. The AF-GEOSpace convention is to label the files *kpNNNN* and *dstNNNN*, respectively, where *NNNN* is the year. Thus the indices for 1991 are stored in the files *kp1991* and *dst1991* in the KP and DST directories noted above, respectively.

It is straightforward to keep the archived data in AF-GEOSpace up-to-date by downloading the most recent NGDC archived data files. The NGDC file containing the indices Kp, SSN, F10.7, and Ap is updated periodically. An example showing how to update Kp, SSN, F10.7, and Ap in the AF-GEOSpace database from the NGDC archive might have been made during March of 2012 is given next. At a Windows command prompt, type

```
cd $AFGS_HOME\models\data\GLOBALS\KP
ftp ftp.ngdc.noaa.gov
 (log in using the username "anonymous" and your local e-mail address as a password)
ftp> cd STP/GEOMAGNETIC_DATA/INDICES/KP_AP
ftp> ls
 (screen listing shows yearly files listed with the latest and smallest being 2012)
ftp> get 2012
ftp> quit
rename kp2012  kp2012old
rename 2012 kp2012
```

The procedure for obtaining Dst data for a given year is similar, e.g., at a Windows command prompt, type

```
cd $AFGS_HOME\models\data\GLOBALS\DST
ftp ftp.ngdc.noaa.gov
 (log in using the username "anonymous" and your local e-mail address as a password)
ftp> cd STP/GEOMAGNETIC_DATA/INDICES/DST
ftp> ls
 (screen listing shows latest file is dst2008.txt)
ftp> get dst2008.txt
ftp> quit
rename dst2008  dst2008old
rename dst2008.txt dst2008
```

Dst files for later years, including periodic updates, can be retrieved from the website for the World Data Center for Geomagnetism in Kyoto Japan (i.e., at http://wdc.kugi.kyoto-u.ac.jp/)

Prelim

When *Prelim* is selected from the *Globals* button, the values of the geomagnetic indices (Kp, SSN, F10.7, Ap) from the near-real time file (see *Latest* below) valid for the *Year*, *Day*, and *Time* values entered in the global parameter boxes are automatically loaded. The data base of near-real time estimates can be used to run AF-GEOSpace for time periods not yet covered by the NGDC archive. Before using *Prelim*, try the *Latest* option to determine the extent of the available data.

Latest

When *Latest* is selected with the *Globals* button, the most recent time and global indices (Kp, SSN, F10.7, Ap) available for the *Year* entered in the global parameter box are automatically loaded from the corresponding file in directory,

$AFGS_HOME\models\data\GLOBALS\RT

The files in this directory contain estimates of the indices as computed by NOAA and can be updated daily (see *Daily Parameters Over the Internet* below). If kept current, the data estimates will be valid for the previous day. File naming conventions and formats are identical to the NGDC archive files, with the exception of a header line giving the data and time of the most recent update. Note that these parameter estimates for a given date often differ from the values that eventually appear in the NGDC archive files. Note: The anonymous ftp script controlled by file *AFGetSec.bat* (see next section) must be executed at least once for the *Latest* function to work.

Daily Parameters Via the Internet

Daily updates of files from NOAA/NGDC containing selected geomagnetic and solar activity indices are available via anonymous FTP from *ftp.sec.noaa.gov* in the directory named *pub/latest*. AF-GEOSpace provides the scripts needed to automatically retrieve these files on a daily basis and use them to update the data file accessed when using the *Prelim* and *Latest*

features described above. The procedure for establishing the daily update is given below and relies on the following files:

$AFGS_HOME\bin\AFGetSec.bat (created during installation)

$AFGS_HOME\bin\AFGetSec.exe

$AFGS_HOME\models\data\Sec\ftpcmd

The batch file *AFGetSec.bat* is created during installation. It sets the two environment variables PLGS_MODELS (location of *bin* and *models* directories) and PLGS_SCRATCH_DIRECTORY (location where FTP files are processed), and calls the executable program *AFGetSec.exe*. Note that the default installation sets PLGS_MODELS=c:\Program Files\AFGeospace and sets PLGS_SCRATCH_DIRECTORY=c:\TEMP

AFGetSec.exe performs an FTP session using input from file *ftpcmd*, then appends the new data from the SEC files to the latest Kp file in $AFGS_HOME\models\data\GLOBALS\RT. Note that the source file for this procedure is *$AFGS_HOME\models\data\Sec\AFGetSec.for*.

Procedure for setting up automated daily parameter updates:

(1) Follow the first set of FTP instructions in the *Archive* section above to place the most recent full Kp file, e.g., file *kp2002*, in the directory $AFGS_HOME\models\data\GLOBALS\KP.

(2) Place a duplicate copy of the most recent full Kp file (obtained in step above) in the directory $AFGS_HOME\models\data\GLOBALS\RT and adjust its properties so that it can be updated (e.g., right-click on file *Kp2002*, select the *Properties* option, and clear the *Read-only* check box).

(3) Edit the second line of file *ftpcmd* to use your e-mail address as the anonymous ftp password. The file can be opened using a text editor like Notepad.

(4) Test the procedure by double-clicking on the file *AFGetSec.bat*. A shell window will appear briefly as the ftp process takes place. If successful, the PLGS_SCRATCH_DIRECTORY will contain five temporary files, e.g., *ftpcmd*, *kp2002*, *MAda.txt*, *sec.bat*, and *SGAS.txt*. File *$AFGS_HOME\models\data\GLOBALS\RT\kp2002* should now contain a new first line (the date) and last line (date and data). If the five new files appear but the Kp file was **not** updated, check that the Kp file *Properties* (right-click on file) are **not** set as *Read-only* and test again.

(5) To establish an automated daily data update, use the Task Scheduler in the Windows Control Panel to run the file *AFGetSec.bat* once daily.

Mouse Buttons

Mouse controls are provided to facilitate manipulation of the 2D and 3D window view and display environment window options and color bars associated with displayed graphical objects.

Left: Depress the left mouse button and move it around while its pointer is within a 3D window to rotate displayed objects.

Right: Depress the right mouse button and move it toward/away from the screen while its pointer is within a 2D or 3D window to expand/contract the view, i.e., to zoom.

Shift+Left: While depressing the *Shift* key, apply the left mouse button and move its pointer around within a 3D window to translate the view in the X, Y, or Z directions and move it around. In a 2D window, this same combination can be used to re-center the Earth map display. Users with an *Intellimouse* can also depress the mouse's center wheel to perform this translate function.

Ctrl+Left: While depressing the *Ctrl* key, use the left mouse button to click on an object in a 2D or 3D window and the related environment window options and color bar will be displayed.

Getting Started

To run AF-GEOSpace, double-click on the AF*Geospace.bat* icon in the $AFGS_HOME\bin folder (or on a shortcut icon if one was created) and three windows will appear: the AF-GEOSpace graphical user interface (GUI) with a set of pulldown menus and two diagnostic screens. The diagnostic windows can be minimized to clean up your desktop, but they must remain open for the application to function properly (for some modules, the diagnostic window will contain run-time messages). To optimize the quality of the GUI layout, it is best to maximize the AF-GEOSpace GUI window. The *Help* menu will guide you to the PDF version of this document.

To start using AF-GEOSpace Version 2.5.1 most effectively, review the *MENUS* section of this manual and then go directly to the *EXAMPLES* section. The examples contain step-by-step instructions that will guide you through a complete AF-GEOSpace session that includes the generation and visualization of space environment parameters. The *Exit* option in the *File* menu terminates AF-GEOSpace and deletes all objects and graphics created during the session.

All comments regarding the current capabilities of AF-GEOSpace and ideas for future versions of the software are appreciated. Contact information is in the *PRODUCT INFORMATION* section at the end of this document.

MENUS

The menu bar at the top of each environment provides access to functions for managing science, application, data, and graphics modules; create graphics windows, and access help. This section describes the File, Edit, View, Module, Window, Viewport, Globals, and Help menus in turn.

File Menu

The *File* menu provides access to features enabling the user to load MHD simulation data files for viewing, save/open completed model runs, save/open window views, save window graphics, and exit an AF-GEOSpace session. The *File* menu button accesses the following options.

Open Paramesh

The *Open Paramesh* function allows the user to read-in or load MHD simulation run results produced externally to AF-GEOSpace using large-scale parallel grid generation and MHD science codes developed by the Navel Research Laboratory (NRL) for the Common High Performance Computing (HPC) Software Support Initiative (CHSSI) collaborative project under way with AFRL. Each simulation is stored in an individual folder in the form of a *flicks.hdr* file, a *flicks.ftr* file, and a numbered set of *flicks.#####* files with one file for each time step. The *Open Paramesh* function produces a popup window for locating the folder containing the data files for the simulation of interest. Selecting the *flicks.hdr* file within a folder and using the *Open* button in the popup window will load the saved data files and place an NRLMHD entry in the *Active Modules* list of the Science Environment Window. The data will then be available for display using the *Paramesh* related graphics modules within a special Heliospace viewport. Create a Heliospace viewport by changing any active window by using the *Viewport* menu and selecting *Projection* and then the *Heliospace* options. More details regarding a description of and access to *Paramesh* data files can be found at the NRL website (*http://www.lcp.nrl.navy.mil/hpcc-ess/amrmhd3d.10.html*) or by contacting the AF-GEOSpace team at AFRL. An AF-GEOSpace session entitled "HELIOSPACE: Loading and Viewing PARAMESH Files" is described in the EXAMPLES section at the end of this manual.

Open Model

The *Open Model* function allows the user to read-in or load Environment Window inputs and run results of previously saved Science and Application modules. Modules are saved as single Common Data Format (CDF) files using the *Save Model* function (see below).

The *Open Model* function produces a popup window for selecting from existing CDF files. Selecting a *.cdf file and using the *Open* button in the popup window will load the saved module and place an appropriate entry in the *Active Modules* list of either the Science or Application Environment Window. The data produced by the module is then available for display using the graphics modules. Note that while the original grid settings do not appear when the new entry in the *Active Modules* list is selected and the *Edit* menu *Grid Tool* option (see below) is selected, the grid information is stored internally. For modules producing only text output, the *Show Text* button in the Environment Window of the reloaded Science or Application module must be selected to see the output.

Before opening a static model run, the appropriate *Start* time should be re-enterer in the text fields at the top of the window and the *Globals:Archive* feature should be selected.

Before opening dynamic model runs, the appropriate *Start* and *End* times should be re-entered in the text fields at the top of the window and the *Globals: Archive* feature should be

-reselected. Then when using the *Animate Tool* (in the *Edit* pulldown menu), the *Range Times* button can be used to automatically set its *Time Start* and *Time End* fields.

For both the static and dynamic run cases, it is very convenient to store all saved model files representing a particular time period in a directory with a name containing a time label (see hint in *Save Model* section below).

Open View

The *Open View* function allows the user to load a view saved previously using the *Save View* function described below. The *Open View* function produces an *Open* popup window for selecting from existing view files (no specific file suffix required). Select a view file and use the *Open* button in the popup window to reset the view of the active 3D window to match the saved view.

Save Model

The *Save Model* function allows the user to save Environment Window input settings and run results of Science and Application modules as single CDF files for future use. This feature works for modules run in both static and dynamic modes. Saved models can be reloaded using the *Open Model* function described above.

To save a model run: (1) Select/highlight a science or application module entry in an *Active Modules* list for a module that has been run, i.e., the message MODEL IS READY AND UP TO DATE must appear in the *Model Status* window at the bottom of the Environment Window. Note that graphics, data, and worksheet module results cannot be saved. (2) Access the *Save Model* option in the *Edit* pulldown menu and a *Save As* popup window will appear. Locate the directory for storing the CDF to be created, enter a file name, and click the *Save* button. When the *Save As* window disappears, the inputs and data from the run module have been written to a CDF file in the designated directory and can be accessed in the future using the *Open Model* feature described above.

Hint: It is suggested that models representing a particular time period be saved together in a directory named to designate the time period, e.g., one might place saved model runs in a directory called "1995_185_0000to1400by7200" to represent a run made for UT=00:00 to 14:00 on day 185 of year 1995 using a dynamic step size of 7200 seconds. This will make viewing and animating the saved output much simpler after using the *Open Model* feature described above. Note that the *Exit* option of the *File* pulldown menu removes all files located in folders generated by AF-GEOSpace during a session so it is best to place CDF files elsewhere.

Save Window As

The *Save Window As* function is used to save the contents of the active window in Tagged Image File Format (TIFF) or Joint Photographic Experts Group (JPEG) format. This feature opens a *Save As* window to specify the format, file name, and save location. While TIFF images are sharper than JPEG images, they also result in much larger files. Note that the *Exit* option of the *File* pulldown menu removes all files located in folders generated by AF-GEOSpace during a session so it is best to place saved graphics files elsewhere.

Save View

The *Save View* function is used to save the view currently visible in an active 3D window. This feature opens a *Save As* window to specify the file name (no specific file suffix required) and save location. No specific file suffix is required. After a view is saved, and the Earth has been moved for example, the saved view can be restored by using the *Open View* function described above. Note that the *Exit* option of the *File* pulldown menu removes all files located in folders generated by AF-GEOSpace during a session so it is best to place saved view files elsewhere.

Print (or *Ctrl*+P)

The *Print* function is currently inactive, i.e., it prints blank pages. To print a window's contents, use the *Save Window A*s option above and then imbed the saved TIFF or JPEG images in another file for printing. To print the entire screen, use the Print Screen Key (*PrntScrn* or *PrtScn*) to capture the entire screen in the buffer and then "paste" it into another document for printing.

Print Preview

The *Print Preview* function is currently inactive.

Print Setup

The *Print Setup* function displays the standard Windows Print Setup window.

Exit

The *Exit* function terminates the program and deletes all session folders in the assigned scratch folder that were created by AF-GEOSpace. Files generated using the *Save Model*, *Save Window As,* and *Save View* functions should not be stored in these temporary session folders if they need to be accessed in the future.

Edit Menu

The *Edit* menu provides access to features enabling the user to run models, delete models, rename entries in the *Active Modules* lists, examine text representations of module produced data, setup computation grids, set dynamic run mode time step values and parameter selection, and animate results from dynamic module runs (including satellite orbits in static mode). The *Edit* menu accesses the following options.

Run/Update (or *Ctrl*+R)

The *Run/Update* function is used to run Science, Application, and Data modules after setting all desired inputs. A *Process View* popup window will appear indicating that the module is running and will disappear when complete. A message in the *Model Status* window at the bottom of the environment window will read that the "MODEL IS READY AND UP TO DATE" to indicate that the generated data are available for use by the graphics modules. Depending on the type of module run, the *Model Status* window may also provide a brief message regarding the time of the run and the global parameters used. A scroll feature enables the user to view longer text outputs to the *Model Status* window.

Delete (Active Module)

The *Delete* function is used to remove entries from the *Active Modules* lists. When displayed graphics modules are deleted, the graphic will disappear from the viewport the next time the window is accessed. Before deleting active Science, Application, or Data modules, all related graphics displays must be removed (popup warnings are displayed if this is not done).

Rename

The *Rename* function enables the user to rename entries in the *Active Modules* lists. A *Rename Model* popup window will appear containing an editable text box for entering a new name for the module. This feature is convenient, for example, when multiple coordinate slices (produced using the Coord Slice graphics module) representing multiple types of science model data appear in the active graphics modules list.

Data Tool

The *Data Tool* function provides an interface to view a data set in a formatted, tabular output form. Selecting the *Data Tool* function after highlighting a science or application module in an *Active Modules* list will produce a *Data Viewer* popup window for viewing the data set produced using that module. In order to view three-dimensional data sets in a two-dimensional tabular format, the *Data Viewer* window allows the user to assign one dimension of the dataset to the columns and another dimension to the rows of the tabular output. The data selector appears at the top of the *Data Viewer* window. Dimensions are assigned to *Columns* and *Rows* using the button switches at the bottom of the window. The "slice" (i.e., the third unassigned dimension) at which the columns and rows are extracted is controlled using the lower slider. The user can scan through the two assigned dimensions using the scroll bars immediately adjacent to the text window. The *Done* button retires the *Data Viewer* window.

Grid Tool (or *Ctrl*+G)

The *Grid Tool* option opens a popup window that allows one to specify the type and resolution of the grid used by science and application modules. If the default grid settings are desired then the *Grid Tool* need not be used. After selecting from the *Grid Tool* options described below, clicking the *Apply* button or closing the *Grid Tool* window will generate the grid. The *Cancel* button should be used to exit the *Grid Tool* Window if no grid changes are desired. **Note:** The coordinate labels *Radius,* etc., will change to correspond to the different types of systems chosen. One must close the *Grid Tool* window in order to activate any changes.

The *Grid Tool* options are:

Spacing: Specifies the manner in which the grid spacing is calculated. Choices are:

Linear: Equally spaced grid points along the coordinate direction are generated.

N-S Symm: Symmetrically spaced grid points along the North-South direction are generated and no grid points exist in the equatorial regions (useful for auroral calculations). For example, with a spherical *Geometry* setting the grid points are evenly spaced between the absolute value of the specified minimum and maximum latitudes in both the Southern and Northern hemisphere, e.g., for a minimum latitude of 50° and a maximum latitude of 90°, grid points will be evenly spaced between 50° and 90° North latitude and 50° and 90° South latitude. No grid points will exist between 50° South and 50° North latitude.

Geometry: Specifies the geometry of the grid. Choices are:

Cartesian: generate a grid in Cartesian geometry.

Cylindrical: generate a grid in cylindrical geometry.

Spherical: generate a grid in spherical geometry.

System: Specifies the coordinate system of the grid. The choices are:

GEOC: Geocentric coordinate system: The Z axis is aligned with the north rotational pole, the X axis pierces the Greenwich Meridian on the equator (0 ° Long, 0 ° Lat), and the Y axis is minus the cross-product of X and Z.

GSM: Geocentric solar magnetospheric coordinate system: The X axis points to the Sun. The Z axis is perpendicular to X and lies in the plane containing the magnetic dipole axis. The Y axis completes the right-handed system and is positive towards dusk.

SM: Solar magnetic coordinate system: The X axis is perpendicular to Z and lies in the plane containing the Z axis and the Earth-Sun line. The Z axis is coincident with the magnetic dipole axis. The Y axis completes the right-handed system and is positive towards dusk.

GEI: Geocentric equatorial inertial coordinate system: The Z axis is the same as for the geocentric coordinate system (*GEOC*). The X axis points in the direction of the first point of Aries (vernal equinox). The Y-axis completes the right-handed system. The angle between the X-axis and Greenwich Meridian is set by the UT.

Set (?, ?, ?): For each of the three coordinates, the user must input the grid sizes. Each coordinate contains a selection list for setting combinations of three of the four variables needed to specify this coordinate. The variables are,

Delta: the interval between nodes.

NPoint: the total number of nodes.

Min: the minimum coordinate value.

Max: the maximum coordinate value.

Dynamic Tool

The *Dynamic Tool* allows the user to select the time steps for running science and application modules and choose which data parameters to write to file for viewing dynamic run results. A text box indicates the number of dynamic steps to be taken (maximum allowed is 200), the times at which to run the model, and information regarding global parameters to be used.

To reduce both run time and the size of environment data files created by AF-GEOSpace, the user should take into account the time-dependent nature of the module to be run when selecting the *Time Step*. For example, if a radiation belt model such as CRRESELE is run using the very slowly time-varying IGRF85 magnetic field, then setting *Time Step* to values less than a day (86400 sec) does not improve the accuracy of the CRRESELE science module output. If, however, the same CRRESELE model is run using the dipole tilt-dependent IGRF85/O-P option (that includes an external magnetic field component), a *Time Step* of two hours (7200 sec) could be considered reasonable.

A Dynamic Tool window appears with the following settings:

Variable to write to file: Select: This section shows the available data parameters that can be generated by the selected module. Only those selected will be viewable with the graphics modules. If no parameters are selected, then an Error popup reading “No data selected for output” will appear when a run is attempted.

Time Step (sec): The time between dynamic steps. The selected module will be run once at each time step.

Update List: The *Update List* button uses the selected *Time Step* to adjust the number of times a model is run within the Start and End times specified at the top of the Environment Window

Done: Exits the *Dynamic Tool*

Animate Tool (or *Ctrl*+A)

Selecting the *Animate Tool* allows the user to animate orbits and data sets in the 1D, 2D, 3D, and Heliospace windows. This tool brings up an *Animate* Window for controlling animation effects. Graphics representing data from science, application, and data modules are updated individually as the animation time slider passes a time at which a model was processed. For example, if the selected *Time Step* is 60 seconds and a satellite position was generated every 60 seconds but magnetic field lines were only produced once every 3 hours, the magnetic field lines will appear to jump suddenly at three hour intervals.

The Animate Window entries are described below.

Time: Text box and slider to set the current date and time.

Animate: Starts/stops the animation stepper at the time indicated by the *Time* slider.

Interactive: When activated, all environments update automatically when the *Time* slider position is changed.

Time Start: Sets the start time for the stepper in day, hour, and minute.

Time End: Sets the stop time for the stepper in day, hour, and minute.

Time Step (Sec): Sets the time increment for the stepper in seconds.

Update: Registers changes made to settings in the *Animate* window.

Range Times: Set the range of the step times from the overall minimum and maximum time for all the dynamic modules used. In static mode, when SATEL-APP is the only dynamic model engaged, the range is set for one day in length beginning with the Start time.

Done: Exits the animation module.

View Menu

The *View* menu button accesses the following options.

Tool Bar

The *Tool Bar* option is currently inactive.

Status Bar

The *Status Bar* is located at the bottom of the Environment Window. It indicates when the interface is ready for input and also indicates the function of some pulldown menu items when selected using the left mouse button.

Module Menu

The *Module* menu provides access to Science, Application, Data, Graphics, and Worksheet modules. Most of the functionality of AF-GEOSpace is accessed via this menu. The *Module* menu button accesses the following options.

Science (or *F2*)

The *Science* option under the modules pulldown menu provides access to the science manager. Once activated, lists of Available and Active Science modules are visible. Science modules may be managed by making appropriate choices from these lists.

Applications (or *F3*)

The *Applications* option under the modules pulldown menu provides access to the application manager. Once activated, lists of Available and Active Application modules are visible. Applications may be managed by making appropriate choices from these lists.

Graphics (or *F4*)

The *Graphics* option under the modules pulldown menu provides access to the graphics module manager. Once activated, lists of Available and Active Graphics modules are visible. Graphical modules may be managed by making appropriate choices from these lists.

Data (or *F5*)

The *Data* option under the modules pulldown menu provides access to the data module manager. Once activated, lists of Available and Active Data modules are visible. Data modules may be managed by making appropriate choices from these lists.

Worksheets (or *F7*)

The *Worksheet* option under the modules pulldown menu provides access to the worksheets manager. Once activated, lists of Available and Active Worksheet modules are visible. Worksheets may be managed by making appropriate choices from these lists.

Window Menu

The *Windows* menu enables the user to create 1D, 2D, and 3D viewports, arrange existing viewports, and view individual viewports in full screen mode. Control of window background colors is also provided. The *Window* menu button accesses the following options.

Create 1D Viewport

Activating the *Create 1D Viewport* option will create a new plot window. The 1D plot windows are designed for displaying line plots of data created by science, application, or data modules. Note that the *Projection* option of the *Viewport* menu can be used to change the dimensionality of any viewport to 1D.

Create 2D Viewport

Activating the *Create 2D Viewport* option will create a new plot window. The 2D plot windows are designed for projection of data created by science, application, or data modules onto a 2D surface (the Earth's surface). Note that the *Projection* option of the *Viewport* menu can be used to change the dimensionality of any viewport to 2D.

Create 3D Viewport

Activating the *Create 3D Viewport* option will create a new plot window. The 3D plot windows are designed for display of 3D data created by science, application, or data modules. Note that the *Projection* option of the *Viewport* menu can be used to change the dimensionality of any viewport to 3D.

Background Colors

The *Background Color* option controls background color of the active viewport which can be set to *Black* (default), *Grey*, *White*, or another arbitrary color using the *Background Color…* option. This last option causes a *Background Color* popup window to appear containing RGB and HSV color sliders and a color wheel option. Move the sliders or simply click the mouse pointer on the color wheel to select the corresponding color.

Full Screen (or *F8*)

The *Full Screen* option displays the contents of the active graphics window in full screen mode. The *Esc* key is used to return the display to its previous state.

Cascade

The *Cascade* option resizes and arranges all windows in an overlapping cascading pattern with the highest numbered window at the front.

Tile

The *Tile* option resizes and shows all windows and completely fills the graphics portion of the GUI.

Arrange Icons

The *Arrange Icons* option organizes all minimized graphics windows and lines them up at bottom of the graphic window space.

1:1, 2:2, 3:3, …

One number entry appears in this menu for each active window. Numbers are assigned in order of window creation. Select a number to bring the corresponding window to the front.

Viewport Menu

Split

Activating the *Split* option will divide the active viewport in the *Horizontal* or *Vertical* direction such that two viewport windows now occupy the space of the original viewport. The two resulting viewports contain the same *Projection* (see next entry) of the original graphical object set.

Projection

The *Projection* option allows the projection of the active viewport to be transformed into a one-dimensional (*One D*) viewport, a two-dimensional (*Two D*) viewport, a three-dimensional (*Three D*) viewport, a special three-dimensional *HelioSpace* viewport used to project Paramesh data, or a special *Spectral* viewport used to display DMSP particle data. Hint: Use the *Create 1D Viewport* option in the *Window* menu and use the new 1D window to plot results if the existing window already contains data. Only graphical objects appropriate to the new dimensionality of the viewport will remain viewable, e.g., the Earth, coordinate slices, and satellite orbits will remain in a viewport whose projection is changed between *Two D* and *Three D*, but none will appear if that same viewport is changed to *One D*. In this latter case, you can quickly view the 2D or 3D graphic objects again by changing the 1-D window back into 2-D or 3-D and redisplaying the existing graphic objects. To do this, select *Graphics* from the *Modules* menu, highlight a graphic object in the *Active Modules* list on the right of the environment window, and click *Display*.

View Position

The *View Position* option is used to set the coordinate frame used for animating *Two D* and *Three D* viewport projections, i.e., for fixing the viewers location relative to a selected coordinate systems. The choices are:

GEOC, **GSM**, **SM**, **GEI**: Select one of these coordinate systems to fix the viewer's perspective. The default setting is GEOC, i.e., the viewer remains at a fixed geographic location. Definitions of these coordinate systems are provided in the *Edit: Grid Tool* menu description above.

View: The *View* option sets the viewing position in both 2D and 3D Viewports

When a 3D viewport is active, selecting the *View* option results in a *View Position 3D: View* popup window with settings for tailoring the 3D view. The options are:

View (*Fixed, Tracking*)

View Positions (*Lat Lon, Noon, Midnight, Dawn, Dusk, UT, North, South, Mag North, Mag South, Satellite, Sun*)

View Position Options (*Latitude, Longitude, UT*)

View Up (*Longitude, Noon, Midnight, Dawn, Dusk, UT, North, South, Mag North, Mag South*)

When a 2D viewport is active, selecting the *View* option results in a *View Position: 2D View* popup window with settings for tailoring the 2D view. The options are:

View Options (*Fixed, Tracking*)

View Position (*Longitude, Noon, Midnight, Dawn, Dusk*, *UT*)

View Position Options (*Longitude, UT*)

Delete (window)

The *Delete* option removes the active portion of split windows. Use the close button at the upper right of each viewport to delete it entirely, but note that the last remaining viewport cannot be deleted.

Color Bar Color

The *Color Bar Color* option controls the text color of the color bar labels. This option causes a *Background Color* popup window to appear containing RGB and HSV color sliders and a color wheel option. Move the sliders or simply click the mouse pointer on the color wheel to select the corresponding color.

Color Bar Tics

The *Color Bar Tics* option is used to adjust the number of minor and major tic marks appearing along the color bar in the active graphics window. Only major tic marks are labeled. After changing the number of tic marks in the popup window, update the color bar by either placing the cursor in the other text box or using the *OK* button.

Show Color Bar

The *Show Color Bar* option is used to remove/replace the color bar appearing on the right side of the active window.

Perspective

The *Perspective* option changes the orthographic projection to a perspective projection, i.e., it shows foreshortening.

Globals Menu

Show

When in dynamic mode (after both a *Start* and *End* time are specified and *Globals:Archive* is used) the *Globals* menu provides read, write, and save access to the global parameters appropriate to the selected time period. A *Globals* popup window will appear showing the parameters Date, Time, Frac_Day, Kp, S_Kp, Ap, SSN, F10.7, Dst, and EqE. See the *Global Parameters* section in this document for details on the definitions and sources for these parameters. These values can be edited and line entries can be added or deleted directly in the text window. The user can then *Apply* and *Save* changes made, *Restore* the original values to the list, or *Cancel* (close the window) using the buttons at the bottom of the *Globals* window. All Science and Application modules run will utilize this same set of global input values (see individual description detailing which global inputs are used by individual modules). **Note**: The *Globals* menu is inactive when running in static mode, i.e., when only a *Start* time is specified. In static mode, the global parameters used to represent the single selected time are contained in the Kp, SSN, F10.7, and Ap text boxes at the top of the Environment window.

Help Menu

The *Help* menu provides access to the AF-GEOSpace User's Manual, software version and point-of-contact information.

About AF-GEOSpace

Displays version number and point-of-contact information.

Manual

Connects the user to an electronic version of this documentation stored in the directory $AFGS_HOME\models\HELP

SCIENCE MODULES

Science modules provide methods for generating data sets from various models of the space environment. The science modules are accessed through the science module manager that becomes visible when the *Science* option in the *Module* pulldown menu is activated. The science module manager consists of two lists - *Available Modules* and *Active Modules*. *Available Modules* are all the modules currently supported by AF-GEOSpace. *Active Modules* are modules that have been created and used by the AF-GEOSpace user during the current session.

Initially, the science module manager will show a list of science modules under *Available Modules*. No science modules have yet been created, so the *Active Modules* list will be empty.

Currently, the following science modules are supported by AF-GEOSpace:

- **APEXRAD:** The APEXRAD space radiation dose model specifies the location and intensity of the radiation dose rate behind four different thicknesses of aluminum shielding for five geomagnetic activity levels as specified by Ap15. It covers the Low Earth Orbit (LEO) altitude region (360-2400 km) and was developed to supplement the CRRESRAD model (see below) which has limited resolution in the LEO regime.
- **AURORA:** The auroral precipitation model specifies the location and intensity of electron number and energy flux, ion number and energy flux, Pederson and Hall conductivities, and the equatorward boundary at 110 km altitude. This module also provides the capability to map flux, conductivity, and equatorial boundary values up magnetic field lines into the three-dimensional magnetospheric grid.
- **CAMMICE:** The CAMMICE/MICS model of the inner magnetosphere plasma population provides pitch angle resolved particle fluxes based on 1-200 keV/q ion data (H+, He+, He++, O<+3, H, He, and O) collected along the Polar spacecraft orbit [1.8 x 9 R_E 90° inclination] from 1996-1999.
- **CHIME:** The CRRES/SPACERAD Heavy Ion Model of the Environment (CHIME) specifies the location and intensity of galactic cosmic rays and/or solar energetic particle fluxes and/or anomalous cosmic ray fluxes.
- **CRRESELE:** The Combined Radiation and Release Effects Satellite (CRRES) electron flux model specifies the location and intensity of electron omnidirectional flux over the energy range 0.5-6.6 MeV for a range of geomagnetic activity levels.
- **CRRESPRO:** The Combined Radiation and Release Effects Satellite (CRRES) proton flux model specifies the location and intensity of proton omnidirectional flux over the energy range 1-100 MeV for quiet, average, or active geophysical conditions.
- **CRRESRAD:** The Combined Radiation and Release Effects Satellite (CRRES) space radiation dose model specifies the location and intensity of the radiation dose rate behind four different thicknesses of aluminum shielding for active or quiet geophysical activity.
- **CUTOFF**: The Geomagnetic Vertical Cutoff Rigidity Interpolation Model (CUTOFF) provides cutoff rigidity values for solar protons and cosmic rays, as a function of the geomagnetic activity index Kp, for altitudes within the Earth's atmosphere (≥ 20 km) to beyond geosynchronous orbit.

- **GCPM:** The Global Core Plasma Model of 2009 is an empirical description of thermal plasma densities (e-, H+, He+, and O+) in the plasmasphere, plasmapause, magnetospheric trough, and polar cap.
- **IONSCINT**: The High Fidelity Ionospheric Scintillation Simulation Algorithm (IONSCINT) model provides realistic scenarios of disruptions in trans-ionospheric radio wave communications with spacecraft due to equatorial scintillation. IONSCINT addresses only intensity (or amplitude) scintillation of 244 MHz signals from geosynchronous satellites.
- **IONSCINT-G**: The GPS Version of the High Fidelity Ionospheric Scintillation Simulation Program (IONSCINT-G) provides realistic scenarios of disruptions in L1 frequency trans-ionospheric radio wave communications with spacecraft due to equatorial scintillation. Sky-maps of the S4 scintillation index are generated for stationary platform locations.
- **IRI2007:** The International Reference Ionosphere (IRI2007) model specifies monthly averages of electron density, ion composition, electron temperature, and ion temperature in the altitude range 50-1500 km.
- **ISPM**: The Interplanetary Shock Propagation Model predicts the transit time of interplanetary shocks from the sun to the Earth and the shock strength upon arrival.
- **MAGNETOPAUSE:** The Magnetopause Model determines if a given point lies inside or outside of the model magnetopause boundary and determines the magnetopause location closest to the point of interest.
- **METEOR IMPACT MAP:** The Meteor Impact Map Model calculates the hourly meteor impact rate or damage rate for a given cross section, pit depth, and material type on a user-specified surface area at positions outside of the Earth's atmosphere. A yearly shower database is used to determine the active showers, their intensity, direction of travel, and mass distribution characteristics.
- **METEOR SKY MAP:** The Meteor Sky Map module calculates the number of visible meteors from active meteor showers (and any user-specified storms) at the specified date, over a grid of ground-level positions covering the entire globe.
- **MSM (Magnetospheric Specification Model):** The Magnetospheric Specification Model (MSM) module generates time-dependent magnetic field values as well as electron, H^+, and O^+ particle fluxes (100 eV to 200 keV) in the inner and middle magnetosphere.
- **NASAELE:** The NASA AE-8 radiation belt models are used to compute the intensity and location of differential omnidirectional electron flux for ten energy intervals between 0.5 and 6.6 MeV which correspond to the ranges of the CRRES HEEF instrument.
- **NASAPRO:** The NASA AP-8 radiation belt models are used to compute the intensity and location of differential omnidirectional proton flux for 22 energy intervals between 1 and 100 MeV which correspond to the ranges of the CRRES PROTEL instrument.
- **NRLMSISE-00:** The NRLMSISE-00 empirical model computes atmospheric number densities of He, O, N_2, O_2, Ar, H, and N, plus total mass density and temperature. Anomalous oxygen number density, i.e., hot atomic oxygen (O_h) or atomic oxygen ions (O^+) present at high altitudes (> 500 km), and exospheric temperature are also calculated.

- **PIM (Parameterized Ionospheric Model):** A global ionosphere model generating electron number density as well as maps of total electron content (TEC), Height of E and F2 peaks (HE, HF2), and plasma frequencies at the E and F2 peaks (FoE, FoF2) as a function of a variety of geophysical activity indices.
- **PPS (Proton Prediction System):** Provides forecasts of the intensity and duration of solar proton events.
- **SAAMAPS-2007:** South Atlantic Anomaly Maps (SAAMAPS) of flux intensities for protons (> 23, >38, >66, and >94 MeV) were created for the epoch 2000-2006 based on data from the Compact Environment Anomaly Sensor (CEASE) flown onboard the TSX-5 satellite (410 km x 1710 km, 69 degree inclination orbit).
- **SEEMAPS-1998:** Normalized flux and dose data for protons with energy > 50 MeV from the APEX and CRRES satellites were used to produce contour maps of relative probabilities of experiencing Single Event Effects (SEEs) in the Earth's inner radiation belts.
- **STOA (Shock Time-of-Arrival Model):** Predicts the transit time of interplanetary shocks from the sun to the Earth. STOA is a predecessor of ISPM.
- **TPM-1 (Trapped Proton Model):** The Trapped Proton Model (TPM-1) provides a solar-cycle dependent low-altitude extension to the CRRESPRO trapped energetic proton model.
- **WBMOD (WideBand Model):** An RF ionospheric scintillation model specifying S4, SI, and other scintillation parameters between any location on the globe and a satellite above 100 km altitude at any frequency above 100 MHz as a function of a variety of geophysical activity indices.

Running Science Modules

To run a science module, use the mouse to select the *Science* option in the *Module* pulldown menu and *Available Modules* and *Active Modules* lists will appear in the Environment Window. Click on the desired choice under *Available Modules*. For example, to create a new version of CRRESELE, click the mouse on *CRRESELE* in the *Available Modules* list. Choosing a science module will do two things: first, the choice is added to the *Active Modules* list; second, the options associated with the chosen science module will appear in the Environment Window. In general, each science module will have a different Environment Window representing the module specific inputs. Adjust the module inputs as required. Before actually running the module, the following two adjustments might be considered which can effect run time and the size of the output files.

First, the *Grid Tool* option in the *Edit* pulldown menu can be used to modify the grid to be filled with data using the selected science module.

Second, the *Dynamic Tool* option in the *Edit* pulldown menu can be used to adjust both the time step to be used and the specific output parameters to be calculated if a *Start* and *End* time have been set at the top of the window, i.e., the run is dynamic. For static runs only a *Start* time is specified and all output parameters are calculated by default.

Finally, the *Run/Update* option in the *Edit* pulldown menu is used to run or re-run the module after any settings have been changed. When the module run is complete a message stating that the MODEL IS READY AND UP TO DATE will appear in the *Model Status* box at the bottom of the Environment Window. At this point, the data produced is ready for display using graphical modules.

Also, the *Delete* option in the *Edit* pulldown menu is used to remove the highlighted science module member of the *Active Modules* list. Note that all active graphics objects must be removed before the science module used to generate their data can be removed.

The APEXRAD Science Module

Model Name: APEXRAD

Version: 15 September 1997; IGRF updates 2009

Developer: Air Force Research Laboratory and AER, Inc.

References: Bell, J.T., and M.S. Gussenhoven, APEXRAD Documentation, *PL-TR-97-2117* (1997), ADA 331633

Gussenhoven, M.S., E.G. Mullen, D.A. Hardy, D. Madden, E. Holeman, D. Delorey, and F. Hanser, Low Altitude Edge of the Inner Radiation Belt: Dose Models from the APEX Satellite, *IEEE Trans. Nucl. Sci., 42*, 2035 (1995)

Gussenhoven, M.S., E.G. Mullen, J.T. Bell, D. Madden, and E. Holeman, APEXRAD: Low Altitude Orbit Dose as a Function of Inclination, Magnetic Activity and Solar Cycle, *IEEE Trans. Nucl. Sci., 44*, 2161 (1997)

Hanser, F.A., and P.R. Morel, Analyze Data from the PASP Plus Dosimeter on the APEX Spacecraft, *PL-TR-96-2088* (1996), ADA 311336

Mullen, E.G., M.S. Gussenhoven, J.T. Bell, D. Madden, E. Holeman, and D. Delorey, Low Altitude Dose Measurements from APEX, CRRES, and DMSP, *Advances in Space Res., 21*, 1651 (1997)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

APEXRAD Overview

The APEXRAD module is a PC program APEXRAD developed and released by the Air Force Research Laboratory. APEXRAD has been produced to supplement the higher altitude CRRESRAD dose models. The following description of APEXRAD is excerpted from the APEXRAD Documentation:

> "APEXRAD uses empirical models based on data from the APEX/PASP+ dosimeter to predict the amount of radiation received in a user specified orbit behind four different aluminum shielding thicknesses. The Advanced Photovoltaic and Electronics Experiments (APEX) Satellite was operational from 3 Aug 94 to 2 Jun 96, just prior to solar minimum. APEX was in an elliptical orbit with a 70^{o} inclination, a perigee of 362 km and an apogee of 2544 km. The instrument used to measure accumulated dose was the APEX Space Radiation Dosimeter which measures both dose rate and accumulated dose in four silicon detectors, each of which is behind an aluminum shield of a different thickness (*Gussenhoven et al*., 1995; *Gussenhoven et al.*, 1997; *Mullen et al.*, 1997). One shield was a 4.28 mil thick slab of Al. The other three were hemispheres of Al with thicknesses of 80.1, 225.8 and 444.4 mils. [...] The minimum energies required for particles to penetrate the shields and accumulate dose in the silicon detectors underneath are 0.15, 1, 2.5, and 5 MeV [respectively] for electrons and 5, 20, 35, and 50 MeV for protons [respectively] (*Hanser and Morel*, 1996). Dose from particles depositing 0.05-1

> MeV and 1-10 MeV is accumulated in two different channels called LOLET and HILET respectively. Contributions to HILET dose are primarily from protons with energies of 5-125 MeV, but electrons with energies >5 MeV may contribute during large electron enhancement periods. Contributions to LOLET dose are from electrons, bremsstrahlung, and protons with energies >80MeV. Dosimeter data are available for approximately 14 of the 22 months that APEX was operational."

The APEXRAD science module is used to map the radiation dose rate models from the APEX mission into a three-dimensional grid specified by the user. A variety of magnetic field models can be used for the mapping. Six dose rate models were derived from the APEX data as described by the following excerpt from the APEXRAD User's Manual:

> "The dose models used by APEXRAD are based on in-situ dose rate measurements made on board the APEX satellite [as described in the excerpt above]. The delta dose measured by the dosimeter over the 24-second intervals was used to build the APEXRAD models. A background subtraction is performed to remove the dose due to constant sources, which include both the on-board alpha source used for calibration, and cosmic rays (*Gussenhoven et al.,* 1997). The measured dose rates for each dome were binned by L and B/B0 to make average dose rate models in rads (Si) per second. The width of each bin in L is 1/100 RE, and the width of each bin in B/B0 is one degree of acrsin (B/B0)-1/2 (approximately 0.75^{o} latitude in a dipole field). The bins form a two-dimensional array of 500 (L) by 90 (B/B0) and over L values of 1 to 6 RE and magnetic latitudes of 0^{o} to ~60^{o}. Many of these bins do not contain data because APEX was in a low altitude orbit and only reached high L values at high B/B0's. To save storage space most of the empty data bins are not stored as part of the models.
>
> Six sets of APEXRAD models were produced. The first set of models is the entire mission average. The other five sets of models are based on the Earth's magnetic activity as recorded by Ap15, a fifteen day running average of the Ap index. The location and intensity of the outer belt horns is dependent on the magnetic activity. Higher activity levels coincide with a significant increase in the LOLET dose rate (up to a factor of 10) where the horns of the outer belt come down to low altitudes. The position of the horns also change[s] with magnetic activity. The HILET dose rate in portions of the inner belt is found to decrease slightly as the magnetic activity increases, however, this decrease is small (less than 20 percent from one activity level to the next) and restricted to the inner edge of the belt. Thus varying magnetic activity has negligible effect on the HILET dose predictions for most orbits. The cumulative effect of varying magnetic activity on total dose received will depend on the orbit. For orbits that pass through the heart of the inner belt[, the] dose from inner belt protons will dominate the total dose and magnetic activity will have little impact. For a certain class of low altitude, high inclination orbits, increases in magnetic activity can lead to a significant increase in total dose rate."

After the user selects which data model is desired, the APEXRAD science module calculates the B/L coordinates of each grid point from the user-specified magnetic field model. The resulting dose rate is then obtained from the B/L coordinates and the chosen data model. That dose rate is assigned to the grid point. In this manner a fully three-dimensional map of the dose rate data may be made from the APEX data.

Warning: Although AF-GEOSpace allows the data to be mapped in three dimensions using a variety of magnetic field models, the original APEX data was binned into B/L coordinates using the IGRF95 magnetic field model. The user should be aware that using other magnetic field models to map the data into three-dimensional space is inconsistent with the original data reduction.

APEXRAD Inputs

The APEXRAD science module requires the user to specify the combination of dosimeter particle energy ranges and aluminum shielding thickness as well as the magnetic activity level and the magnetic field model used in mapping the data.

The APEXRAD options are,

B-Model: The magnetic field model is used to convert from the B-L coordinates of the model to three-dimensional space. The default is the field model used to reduce the APEX data set: IGRF95. The complete options are:

Dipole:	A dipole field
Dipole-Tilt:	A tilted dipole field
Dip-Tilt-Off:	A tilted-offset dipole field
IGRF:	The International Geomagnetic Reference Field with no external contributions.
IGRF/O-P:	The *IGRF* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.
IGRF95:	The International Geomagnetic Reference Field (1995) with no external contributions.
IGRF95/O-P:	The *IGRF95* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.

Shielding: The shielding parameter specifies whether the *4.29, 82.5, 232.5*, or *457.5 mil Al* hemisphere shielding thickness data set is to be used.

Channel: The channel parameter specifies which dose rate data set is to be used:

Lo Let:	(0.05 - 1 MeV)
Hi Let:	(1 - 10 MeV)
Total:	= *Lo Let* + *Hi Let*

Activity: This parameter specifies which of the five flux model sets corresponding to the five geomagnetic activity levels as specified by Ap15 is to be considered, i.e., 5.0 - 7.5, 7.5 - 10, 10 - 15, 15 - 20, or 20 - 25. Also possible is the choice of the mission average (*Whole Mission*) model set.

APEXRAD Outputs

The APEXRAD science module returns a 3D Gridded Data Set of the dose rate in units of rads (Si) per second for the selected shielding level, detector channel, and activity combination.

The AURORA Science Module

Model Name:	Aurora
Version:	September 1998
Developer:	Air Force Research Laboratory
References:	Brautigam, D.H., M.S. Gussenhoven, and D.A. Hardy, A Statistical Study on the Effects of IMF Bz and Solar Wind Speed on Auroral Ion and Electron Precipitation, *J. Geophys. Res, 96*, 5525-5538 (1991)
	Hardy, D.A., W. McNeil, M.S. Gussenhoven, and D. Brautigam, A Statistical Model of Auroral Ion Precipitation 2. Functional Representation of the Average Patterns, *J. Geophys. Res, 96*, 5539-5547 (1991)
	Madden, D., and M.S. Gussenhoven, Auroral Boundary Index from 1983 to 1990, *GL-TR-90-0358*, Phillips Laboratory, Hanscom AFB, MA (1990), ADA 232845
	Hardy, D. A., M.S. Gussenhoven, and D. Brautigam, A Statistical Model of Auroral Ion Precipitation, *J. Geophys. Res., 94*, 370-392 (1989)
	Hardy, D. A., M.S. Gussenhoven, R.A. Raistrick, and W. McNeil, Statistical and Functional Representations of the Pattern of Auroral Energy Flux, Number Flux, and Conductivity, *J. Geophys. Res., 92*, 12275-12294 (1987)
	Hardy, D. A., M.S. Gussenhoven, and E. Holeman, A Statistical Model of Auroral Electron Precipitation, *J. Geophys. Res., 90*, 4229-4248 (1985)
	Gussenhoven, M.S., D.A. Hardy, and N. Heinemann, Systematics of the Equatorward Diffuse Auroral Boundary, *J. Geophys. Res., 88*, 5692-5708 (1983)
	Gussenhoven, M.S., D.A. Hardy, and W.J. Burke, DMSP/F2 Electron Observations of Equatorward Auroral Boundaries and their Relationship to Magnetospheric Electric Fields, *J. Geophys. Res., 86*, 768-778 (1981)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

AURORA Overview

The AURORA science module accesses the set of Air Force Statistical Auroral Models (AFSAM), a compilation of time averaged auroral ion and electron models. These models were derived from precipitating particle measurements made by the SSJ/4 electrostatic analyzers flown on the F6 and F7 satellites of the Defense Meteorological Satellite Program (DMSP). The SSJ/4 analyzers determined the electron and ion spectrum in the local satellite zenith direction once per second over 20 channels spanning the energy range from 30 eV to 30 keV.

Statistical hemispheric particle precipitation maps were created for a range of different magnetospheric activity levels using the same spatial grid defined in corrected geomagnetic latitude (CGL) and magnetic local time (MLT). The high-latitude region grid was defined by 30

zones in CGL between 50^o and 90^o and 48 half-hour zones in MLT. The latitude zones were 2^o wide between 50^o and 60^o and 1^o wide between 60^o and 80^o latitude.

For a given level of activity, one-second spectra were accumulated in the CGL x MLT spatial grid defined above. For each spatial element, the average value of precipitating particle flux (electrons or ions) in each of the energy channels were then determined, and the resulting average spectra extrapolated to 100 keV. The large size of the DMSP data set ensured that a reasonable number of individual 1-s spectra occurred in each spatial element traversed by the satellite such that a statistically meaningful average spectrum could be determined. From these final differential number flux spectra, a number of key parameters were derived, including integral number flux, integral energy flux, average energy (ratio of integral energy flux to integral number flux), and the height-integrated Hall and Pedersen conductivities. To calculate the conductivities, we used the functional relations of *Spiro et al*. [*J. Geophys. Res., 87*, 8215, 1982] as corrected by *Robinson et al*. [*J. Geophys. Res., 92*, 2565, 1987].

The AFSAM models are separated according to (1) the magnetic activity index Kp and (2) the z-component of the interplanetary magnetic field (IMF Bz) in combination with the solar wind speed (Vsw). For the Kp model, there are 7 maps separated by whole values of Kp, i.e., one determination for Kp = 0, 0+, one for Kp = 1-, 1, 1+, etc., up to Kp= 5-, 5, 5+. One final separation is made for all cases with Kp >= 6-. For the Bz/Vsw model, there are 30 maps defined by the paired combinations of the 6 Bz values (-4.5, -2.2, -0.7, 0.7, 2.2, 4.5 nT) and the 5 Vsw values (346, 408, 485, 572, and 677 km/s).

The original Kp electron model [*Hardy et al*., 1985] was constructed using data from the older SSJ/3 spectrometers flown on the DMSP F2 satellite and the P78-1 satellite. This model was followed by the Kp ion model [*Hardy et al.*, 1989] which was constructed using data from the newer SSJ/4 spectrometers flown on DMSP F6 and F7 satellites. For consistency, the original Kp electron model has been updated by a newer model (identical format) constructed from the same F6/F7 database which was used for the Kp ion model. The most recent AFSAM models are the Bz/Vsw models for both electrons and ions [*Brautigam et al.*, 1991].

AF-GEOSpace uses analytic representations of the key parameters derived from the average spectra and noted above. At this point, the reference for the analytical fits to the most current models has not yet been published in its complete form. However, the original reference for the Kp ion model fits to integral number flux and integral energy flux [*Hardy et al.*, 1991] remains valid. A publication referencing the complete set of AFSAM model fits is forthcoming.

The output domain of the AFSAM models is a two-dimensional (MLT, CGL) grid located at 110 km altitude (1.017 Earth radii). The default output grid in AF-GEOSpace is the AFSAM two-dimensional grid mapped to three-dimensional geocentric coordinates (GEOC) at an altitude of 110 km and at the time and activity level specified by the Global Parameter Kp or Bz/Vsw. Though the nominal altitude of the DMSP satellites is 840 km, the measured fluxes were mapped down the magnetic field lines to 110 km (the base of the ionospheric E layer) before constructing the AFSAM models.

The AF-GEOSpace AURORA science module extends the AFSAM models by providing the capability to map into three dimensions the magnetic field lines that intersect constant flux or conductivity contours on the two-dimensional model grid. This is done as follows: for each grid point in the user-specified three-dimensional grid, the unique magnetic field line intersecting this

point is traced down to the original two-dimensional model domain at 110 km using a user-specified magnetic field model. The grid point is then given the flux (integral number or integral energy flux), average energy, or conductivity value existing at the point of intersection between the field line and the original model domain at 110 km. By using the ISOCONTOUR or COORD-SLICE graphics objects on the resultant 3D AURORA dataset, magnetic field lines surfaces intersecting contours of constant flux in the original model domain can be easily visualized.

Note: The value of the flux, average energy, or conductivity specified by AF-GEOSpace at any altitude other than 110 km is NOT necessarily a meaningful value for that quantity. AF-GEOSpace uses the flux values on the three-dimensional grid above 110 km to denote sets of field lines emanating from the respective flux value isocontours at 110 km. The actual physical processes involved in determining the variation of flux values along the magnetic field lines have not been considered.

Also contained in the AURORA science module is an algorithm to determine the equatorward boundary of the aurora at 110 km altitude and map it along field lines generated by a user-specified magnetic field model. The algorithm represents a linear fit between the equatorward boundary (in the CGL coordinate) of the electron integral number flux and the Kp index for 24 sectors in MLT [*Gussenhoven et al.*, 1981; *Gussenhoven et al.*, 1983]. AF-GEOSpace uses the coefficients determined from over 200,000 DMSP boundary crossings in the interval 1983-1990 [*Madden and Gussenhoven* 1990]. Options are given to either (a) input Kp and output the entire equatorward edge boundary or (b) input a single observation of the equatorward edge in CGL and MLT (e.g., from one DMSP satellite crossing) and output the entire equatorward edge boundary. In the latter case, an “effective Kp” is computed by inverting the linear regression relation for the measurement in the single MLT bin and then using the effective Kp to calculate the equatorward edge in the remaining MLT bins.

AURORA Inputs

The Aurora science module requires the Global Parameters: Year, Day, UT, and Kp.

Note: When a 3-D grid is chosen, magnetic field model inputs necessary for magnetic field line mapping are required to be specified in the *Internal Field* and *External Field* sections outlined below. Additional information and references on the magnetic field models can be found in the BFIELD-APP section of the documentation.

The *Generate* section allows the user to produce the following output data sets:

Gridded Data: A set of 3D Gridded Data Sets for auroral electron number flux, electron energy flux, ion number flux, ion energy flux, electron average energy, ion average energy, Hall conductivity, and Pedersen conductivity is produced. The default settings for the Grid define a two-dimensional geocentric coordinate slice at the constant radius of 110 km (1.017 Re). When a three-dimensional Grid is specified with the Grid Tool, the data values from the default two-dimensional slice are mapped to the grid points along field lines determined from the user-specified magnetic field model.

Eq Edge: Field Line data sets are produced that represent the equatorward edge of the auroral electron number flux boundary and its mapping out along magnetic field lines of the user-specified magnetic field model. The following options become applicable:

Use Kp or IMF/SW Model: If this option is selected the AURORA science module calculates the equatorward boundary using the Kp or IMF/SW option described below in the *Model* section. For dynamic runs, Kp inputs are those listed using the *Globals* menu *Show* option while IMF/SW selections remain constant.

Use single observation: If this option is selected the AURORA science module calculates the equatorward boundary by determining an effective Kp from a single MLT observation of the boundary location. The effective Kp is then applied to determine the boundary for the remaining MLT points. For dynamic runs, the selected settings remain fixed. If selected, the following quantities must be entered,

MLT: The magnetic local time of the observation in decimal hours.

Observed MLAT: The magnetic latitude in Corrected Geomagnetic Coordinates of the observed equatorward boundary at the specified MLT. Typical values of this parameter for midnight local time (MLT = 0.0) can be viewed using the *Globals* menu *Show* option when a dynamic run is performed.

Note: If the effective Kp determined from the *MLT*, *Observed MLAT* values entered is outside of the acceptable range (Kp = 0.0 to 9.0) or if the *Observed MLAT* value entered is not valid for the selected *MLT* value, then an error popup window will warn the user. To best resolve this, select the *Use Kp* option and set the global Kp value equal to either 0.0 or 9.0, whichever is appropriate.

Map from North: Magnetic field line mapping originates from the auroral equatorward boundary in the northern hemisphere.

Map from South: Magnetic field line mapping originates from the auroral equatorward boundary in the southern hemisphere.

Note: Magnetic field lines emanating from the northern hemisphere auroral equatorward boundary will not generally match those emanating from the southern auroral boundary. This is because no magnetic field model in AF-GEOSpace exactly matches the models used to construct CGM coordinates. The closest match arises when using the IGRF internal field for the year 1990 without an external field.

The match is not exact due to interpolation and function fitting of the CGM coefficients in the CGM to geographic coordinate conversion routine used.

The *Internal B-Field* section allows the user to specify which model to use for the Earth's internal magnetic field: *Dipole, IGRF(1945-2010)*, or *Fast IGRF.* Additional information and references on the magnetic field models can be found in the BFIELD-APP section of the documentation.

The *External B-Field* section allows the user to specify which model to use for external contributions to the magnetic field: *None, Hilmer-Voigt, Olson-Pfitzer, Tsyganenko '89,* or *Tsyganenko '87*. Additional information and references on the magnetic field models can be found in the BFIELD-APP section of the documentation.

The *Model* section allows the user to specify the data to drive the model. The options are:

Kp: Selects the Kp index from the Global parameters as the model driver.

IMF/SW: Selects the interplanetary magnetic field and solar wind data as model driver. When this option is chosen the following quantities must be entered:

- Bz(nT): The value of the z-component of the interplanetary magnetic field available as six selectable values from -4.5 to 4.5 nanotesla (nT).
- Vsw(km/s): The value of the magnitude of the solar wind velocity available as five selectable values between 346 and 677 kilometers/second (km/s).

AURORA Outputs

When the Gridded Data output option is selected the AURORA science module returns the integral electron energy flux (keV/(cm^2 s sr)), the integral electron number flux (#/(cm^2 s sr)), the integral ion energy flux (keV/(cm^2 s sr)), the integral ion number flux (#/(cm^2 s sr)), the electron average energy (keV), the ion average energy (keV), the height-integrated Pedersen conductivity (mhos), and the height-integrated Hall conductivity (mhos) as separate 3D Gridded Data Sets. In the default mode, the 3D Gridded Data Set will contain only a two-dimensional constant radius slice at an altitude of 110 km (1.017 Re). When the user specifies a three-dimensional grid with the Grid Tool, a grid point is assigned a value equal to the data value existing at the point of intersection between the original constant-radius data slice at 110 km and the magnetic field line that maps through the point in question. It is thus possible to denote surfaces of field lines emanating from separate flux value isocontours at 110 km.

When the *Eq Edge* output option is selected the AURORA science module returns a Field Line Data Set containing magnetic field lines emanating from the equatorward edge of the auroral electron number flux (referred to as *Mapped Eq. Edge* in the data selection list). An additional Field Line data set is generated representing the equatorward edge oval (referred to as *Eq. Edge*).

The CAMMICE Science Module

Model Name: CAMMICE

Version: August 2010

Developer: AER, Inc. and Air Force Research Laboratory (based on particle flux database files provided by J.L. Roeder of The Aerospace Corporation)

References: Olson, W.P., and K.A. Pfitzer, A Quantitative Model of the Magnetospheric Magnetic Field, *J. Geophys. Res., 79*, 3739 (1974)

Olson, W.P., and K.A. Pfitzer, Magnetospheric Magnetic Field Modeling, Annual Scientific Report, Air Force Office of Scientific Research contract F44620-75-C-0033, McDonnell Douglas Astronautics Co., Huntington Beach, CA (1977), ADA 037492

Roeder, J.L., M.W. Chen, J.F. Fennell, and R. Friedel, Empirical Models of the Low-Energy Plasma in the Inner Magnetosphere, *Space Weather, 3*, S12B06, doi:10.1029/2005SW000161 (2005)

Russell, C.T., R.C. Snare, J.D. Means, D. Pierce, D. Dearborn, M. Larson, G. Barr, and G. Le, The GGS/Polar Magnetic field Investigation, *Space Sci. Rev., 71*, 563-582 (1995)

Schulz, M., and L.J. Lanzerotti, *Particle Diffusion in the Radiation Belts*, Springer, New York, (1974)

Scudder, J., et al., Hydra---A 3-dimensional electron and ion hot plasma instrument for the Polar spacecraft of the GGS mission, *Space Sci. Rev., 71*, 459-495 (1995)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

CAMMICE Overview

The CAMMICE science module provides an implementation of the CAMMICE/MICS empirical plasma flux model described by *Roeder et al.* [2005].

> "Data from two instruments on the Polar satellite [1.8 x 9 R_E orbit with a 90° inclination and an 18-hour period] were used to construct a model of the charged particle environment. The Magnetospheric Ion Composition Spectrometers (MICS) was part of the Charge and Mass Magnetospheric Ion Composition Experiment (CAMMICE) on the Polar satellite. MICS measured all positively charged ion species ranging in mass from hydrogen to iron in the range 1-200 keV/e. […] The CAMMICE/MICS data were supplemented by measurements from the Hydra instrument, also on the Polar mission. Hydra measured ion and electron flux in the range 2 eV/e to 35 keV/e [*Scudder et al.,* 1995]."

Multiple equatorial data sets were derived from the CAMMICE/MICS data as described by this additional excerpt from *Roeder et al.*:

> "The CAMMICE/MICS data for 3.5 years (March 1996 to September 1999) were averaged into 5-min distributions in energy and local pitch angle to build the database. The 24 energy steps from the MICS instrument were combined into 12 channels by averaging the fluxes for every other step to improve statistics. The local pitch angles for each measurement were computed using the simultaneous data from the Polar magnetic field experiment [*Russell et al,* 1995]. The local pitch angle distribution for each energy was averaged into 18 equally spaced bins of 10° widths. Then the local pitch angles were converted into equatorial pitch angles using the ration of the measured local magnetic field magnitude to the equatorial magnetic field magnitude [*Schulz and Lanzerotti*, 1974]. The equatorial magnetic field was calculated for this purpose using the IGRF model of the geomagnetic field. The equatorial pitch angle distribution at each energy was then averaged into spatial bins in equatorial magnet coordinates. The magnetic equatorial plane was divided into a grid of 16 equally space bins in L in the range 2-10 and 2-hour bins in MLT."

An additional complete set of data files were also created by the authors which exclude data obtained during geomagnetically active intervals, i.e., to represent quieter conditions when the geomagnetic index Dst > -100 nT.

The CAMMICE module is used to map the ion flux data sets onto a three-dimensional grid specified by the user. Two different magnetic field models can be used for the mapping. After selecting an ion species, a geomagnetic Dst activity option, and a pitch angle range of interest, the module calculates the B/L coordinates for each grid point in the user-specified magnetic field model. Resulting flux values are then obtained from the B/L coordinates and the chosen data file and assigned to the grid point. In this manner, a fully three-dimensional map of the ion flux data may be made from the CAMMICE/MICS equatorial data sets.

CAMMICE Inputs

The CAMMICE science module requires the Global Parameters: Year, Day, and UT.

B-Model: The magnetic field model used to convert from the B-L coordinates of the model to three-dimensional space. The *B-Model* options include:

- IGRF: The International Geomagnetic Reference Field with no external contributions.
- IGRF/O-P: The *IGRF* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.

DST: Two ranges of geomagnetic activity can be specified, namely

- All: This option provides results of the complete data set.
- DST > -100: This option presents results generated from data collected when the Dst index was less negative than -100 nT, i.e., during only geomagnetically quieter conditions.

Species: The particle species available include: *H+, He+, He++, O<+3, H, He, O,* and *Ions* (includes all ions irrespective of mass or charge state and are assumed to be protons).

Pitch Angle: The equatorial pitch angle distribution options include *Omnidirectional* or one of 18 equally spaced bins of 10° widths, i.e., *0-10, 10-20, …, 170-180* degrees.

CAMMICE Outputs

The CAMMICE Science module returns a 3D Gridded Data Set of the particle flux for the selected species and Dst level in units of (#/cm^2/s/keV) in the following 12 energy channels all in units of keV/q: (1) [1.0-1.3], (2) [1.8-2.4], (3) [3.2-4.2], (4) [5.6-7.4], (5) [9.9-13.2], (6) [17.5-23.3], (7) [30.9-41.1], (8) [54.7-72.8], (9) [80.3-89.7], (10) [100.1-111.7], (11) [124.7-139.1], and (12) [155.3-193.4]. The L-Shell and B/Bo values used to determine off-equator fluxes are also returned.

Note: All species do not have the same energy coverage in the model, therefore particle fluxes for the following [*species*, energy channel] combinations are not part of the CAMMICE Science module output: [*H+*, ch.1-3], [*He+*, ch. 1-5], [*O<+3*, ch. 1-6], [*H*, ch. 8-12], [*He*, ch. 8-12], and [*O*, ch. 9-12].

The CHIME Science Module (Static Only)

Model Name: CRRES/SPACERAD Heavy Ion Model of the Environment (CHIME)

Version: 3.5, December 1995

Developer: Lockheed Martin Advanced Technology Center and AFRL, adapted to AF-GEOSpace by Radex, Inc. (now AER, Inc.)

References: Chenette, D. L., J.D. Tobin, and S.P. Geller, CRRES/SPACERAD Heavy Ion Model of the Environment, CHIME, *PL-TR-95-2152*, Phillips Laboratory, Hanscom AFB, MA (1995) (User's guide for Version 3.5), ADA 321996

Chenette, D.L., J. Chen, E. Clayton, T.G. Guzik, J.P. Wefel, M. Garcia-Munoz, C. Lopate, K.R. Pyle, K.P. Ray, E.G. Mullen, D.A. Hardy, The CRRES/SPACRAD Heavy Ion Model of the Environment (CHIME) for Cosmic Ray and Solar Particle Effects on Electronic and Biological Systems in Space, *IEEE Trans. Nucl. Sci., 41*, 2332-2339 (1994)

Feynman, J., G. Spitale, J. Wang, and S. Gabriel, Interplanetary Proton Fluence Model: JPL 1991, *J. Geophys. Res., 98*, 13281 (1993)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

CHIME Overview

The CRRES Heavy Ion Model of the near-Earth Space Environment (CHIME) Science Module and Linear Energy Transfer (LET) Application Module are based on the PC program CHIME developed and released under the auspices of the Air Force Research Laboratory. The following description is excerpted from the CHIME User's Manual:

> "[CHIME] is a set of programs and data files which permit a user to (1) calculate accurate models of the fluxes and energy spectra of ions in the near-Earth space environment under a wide variety of conditions, (2) convert these particle flux models to linear energy transfer spectra, and (3) estimate rates for single-particle radiation effects in microelectronic devices exposed to the environmental model fluxes.... The [environment] model covers the energy range from 10 MeV/nucleon to 60 GeV/nucleon for all known stable elements, and includes the known major sources of heavy ions in the near-Earth interplanetary medium over this energy range, namely: galactic cosmic rays (GCR), the anomalous component (AC), and heavy ions from solar energetic particle events (SEP)."

The CHIME Science Module calculates ion flux models (Step 1 in the paragraph above) and produces a 3D data set as a function of geographic coordinates. Calculation of the LET spectra and single event effect (SEE) rates (Steps 2 and 3 in paragraph above) are accomplished in the LET-APP Module. The CHIME Science Module provides an option to normalize the fluxes to the regular CHIME units (particles/(m^2 s sr MeV/nucleon)) or the units used in the CRRESPRO trapped proton model (particles/(m^2 s MeV)). Using the CRRESPRO units, intensities of the cosmic rays and solar energetic particles can be directly compared to the intensity in the radiation belts.

The models for the GCR and AC are described as follows in the CHIME User's manual:

> "The long-term time- and energy-variations of the GCR and AC heavy ions near earth are well understood as the result of "modulation" by the sun of a set of "local interstellar spectra" (LIS) defined at the outer boundary of the heliosphere. The amount of this modulation is described by a single parameter for all particle species: the solar modulation parameter, Φ, which is in units of electric potential, typically megavolts (MV).
>
> CHIME contains a comprehensive [GCR] data base describing the heavy ion flux environment near earth under the full range of expected solar modulation conditions. This database is a set of differential (in energy) heavy ion fluxes as a function of kinetic energy (E) and Φ. The E, Φ range covered by this database is from 10 MeV/nucleon to 60 GeV/nucleon in kinetic energy and 300 MV through 1700 MV in solar modulation level. All ions from hydrogen (Z=1) through nickel (Z=28) are tabulated. Ions heavier than nickel are modeled using abundance ratios to iron. [...]
>
> For the elements He, N, O, and Ne an additional component, the anomalous component (AC), is also tabulated in the database. The AC was calculated using the same solar modulation code and for the same range of solar modulation as the GCR flux. Due to the nature of this source, however, the AC-LIS decrease very rapidly with increasing energy compared to the GCR-LIS. Thus the AC fluxes become insignificant compared to the GCR fluxes above a few hundred MeV per nucleon. Additionally, in the solar modulation calculation the AC was treated as singly charged, and the AC charge state is assumed to be 1 (singly charged) in the calculation of the geomagnetic shielding [described below]."

Solar Energetic Particles are treated in a variety of ways as described in the CHIME User's Manual excerpts that follow.

> "Several different SEP models are incorporated into CHIME. These include models based on measurements made during the CRRES mission and models based on statistical distributions of energetic solar proton event intensities. The user of CHIME may select any one of these models to add to the GCR and AC fluxes determined as described [above]."
>
> "The two largest SEP events observed during the CRRES mission occurred in March and June 1991. Due to the significance of these events to CRRES investigations, they are made directly available for use in CHIME. The March event was an "iron-rich" event, but with a significantly softer energy spectrum than the June event (see *Chen et al.* [*Adv. Space. Res., 14*, 675, 1994] for a more detailed description of these events). Thus for very thin amounts of passive shielding, the March environment was more severe than that for June.... The user can select the peak instantaneous flux or the highest 24-hour average flux for either event."
>
> "For predictive purposes CHIME also provides heavy ion fluence models as a function of mission duration and probability of occurrence. (In this context fluence refers to flux integrated over time.) These models are based on the "Interplanetary Proton Fluence Model: JPL 1991" [*Feynman et al.*, 1993]. This is a statistical description of the observed distribution of energetic solar proton event sizes. For a given mission start date and duration, the model provides a proton fluence spectrum which would be exceeded at a

probability of occurrence, or confidence level, selected by the user (from 50% to 0.1%). Heavy ion fluences as a function of energy are scaled from the proton fluence spectrum using a table of energy independent, average solar energetic particle event, [and] ion composition factors.

It is important to remember that the JPL 1991 model describes ion fluences, which are fluxes integrated over a specific time interval. If a time interval is specified by the user in defining the GCR and AC fluxes, that same interval will be used in the SEP model if the JPL 1991 model is selected."

To compute the GCR, AC, and SEP particle fluxes in the near-Earth region magnetically shielded by the Earth's magnetosphere (taken to be radial distances less than 15 Earth radii in CHIME) a geomagnetic cutoff model is employed as described in the CHIME User's Manual:

"The model is based on an offset, tilted dipole approximation for the earth's magnetic field [*Wilson et al., NASA Ref. Pub. 1257*, 475, 1991]. Despite its simplicity, this model captures the major features of the combined total average geomagnetic shielding effect with good accuracy.... [For each point on the user-specified grid in the CHIME science module], the GEOMAG Transmission function in CHIME calculates the access solid angle as a function of the ion energy and applies this filter function to the interplanetary heavy ion flux calculated by the procedures described [above]... The transmission filter is applied separately to the GCR[+SEP] and AC spectra. While the GCR[+SEP] source is assumed to consist of fully stripped ions (Q=Z), the AC is treated as singly charged (Q=1) in this part of the calculation."

Note: The CHIME science module has not been optimized and can take a significant amount of run time on high-resolution grids.

CHIME Inputs

Input to the CHIME science module comprises the environment inputs required to run the model and the requested particle limits for the output fluxes.

Specify environment:

GCR/AC Flux Input: Several methods for generating cosmic ray fluxes (Galactic Cosmic Rays/Anomalous Component Spectra) are provided. The options are:

- Off: No cosmic ray fluxes generated.
- Modulation: CHIME provides fluxes corresponding to the *Level* (entered in the text box, approximate range: 400 to 1600 megavolts) of solar modulation selected from a full range of monthly values over the period 1970-2010.
- Period: CHIME computes the average of the fluxes for each ion species over the user-specified time interval entered in the *Year 1*, *Day 1*, *Year 2*, and *Day 2* text boxes activated when this option is selected. Tabulated monthly values of the solar modulation parameter for the period 1970-2010 are used.

SEP Events: The CHIME model provides several models for specifying the flux or fluence of heavy ions originating at the Sun as a result of solar energetic particle (SEP) events. The options are:

- Off: No SEP event related flux/fluence is generated.
- March 91 Peak: Model based on peak CRRES measurements from the March 1991 event
- June 91 Peak: Model based on peak CRRES measurements from the June 1991 event
- March 91 Ave: Model based on average CRRES measurements from the March 1991 event
- June 91 Ave: Model based on average CRRES measurements from the June 1991 event
- JPL 1991 Model: Models based on statistical distributions of solar proton event intensities (JPL 1991, *Feynmann et al.,* [1993]). It provides the proton fluence that would be exceeded at a probability level of occurrence (*Pr*), or confidence level, from 50% to 0.1%. If the *GCR/AC Flux* option *Off* or *Period* is selected above, then fluxes are calculated from the fluences using the user-specified time interval. If *Modulation* is selected as the *GCR/AC Flux* option, then a random period of 1 year is used.

Note: The cosmic ray flux input and solar event options are identical to those used in the LET-APP Module.

Galactic cosmic ray (GCR) and solar energetic particles (SEP):

- Atomic Z(1-28): The range (Min, Max) of species atomic Z value. Accepted values range from 1 to 28 AMU.
- Energy(MeV/n): The energy range (Min, Max) of the particles. Accepted values range from 10 to 50000 MeV/n.

The Anomalous component cosmic ray (AC) particles:

- Mass(4-20): The mass range (Min, Max) of the particles. Accepted values range from 4 to 20 AMU.
- Energy(MeV/n): The energy range (Min, Max) of the particles. Accepted values range from 10 to 2050 MeV/n.

Flux Units: Two proton output flux unit options are available. Note that output can be displayed using either units without re-running the CHIME module (see CHIME Outputs section below for details). The options are:

- CHIME: Flux is given in units of #/(m^2 s sr MeV/n).
- CRRESPRO: Omni-directional flux is given in units #/(cm^2 s MeV/n).

CHIME Outputs

The CHIME science module outputs a 3D gridded data set of either the cosmic ray (and/or solar event fluxes) or the anomalous cosmic ray fluxes. Output units are #/(m^2 s sr MeV/nucleon) in CHIME units or #/(cm^2 s MeV/nucleon) in CRRESPRO units.
Note: After generating a graphic object such as a coordinate slice, you can view output in the alternate flux units by doing the following: return to the CHIME Science Module (i.e., go to the *Module* Menu, *Science* option, and highlight the *SciChime* entry in the Active Modules list), reset your *Flux Units* selection, (DO NOT rerun CHIME), return to the graphics object to be updated and then reselect the CHIME data. Use of the CRRESPRO flux unit option will produce much smaller numbers (factor of 10^{-4}) than will use of the CHIME flux unit option. To properly view output in the new units, the color scale range must be adjusted using the *Data Map* options

The CRRESELE Science Module

Model Name:	CRRESELE
Version:	July 1995; IGRF updates 2009
Developer:	Air Force Research Laboratory and AER, Inc.
References:	Brautigam, D.H., and J. Bell, CRRESELE Documentation, *PL-TR-95-2128*, Phillips Laboratory, Hanscom AFB, MA (1995), ADA 301770
	Brautigam, D.H., M.S. Gussenhoven, and E.G. Mullen, Quasi-static Model of Outer Zone Electrons, *IEEE Trans. Nucl. Sci., 39*, 1797-1803 (1992)
	Brautigam, D.H., CRRES in Review: Space Weather and Its Effects on Technology, *J. of Atmos. And Solar-Terr. Phys., 64*, 1709-1721 (2002)
	Olson, W.P., and K.A. Pfitzer, Magnetospheric Magnetic Field Modeling, Annual Scientific Report, Air Force Office of Scientific Research contract F44620-75-C-0033, McDonnell Douglas Astronautics Co., Huntington Beach, CA (1977), ADA 037492

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

CRRESELE Overview

The CRRESELE science and application modules use the PC program CRRESELE developed and released by the Air Force Research Laboratory. The following description of CRRESELE is excerpted from the CRRESELE documentation:

> "CRRESELE utilizes electron radiation belt models constructed from data measured by the High Energy Electron Fluxmeter (HEEF) flown on the Combined Release and Radiation Effects Satellite (CRRES). CRRES flew in a geosynchronous transfer orbit for 14 months during solar maximum. The electron models are omnidirectional flux maps binned in L shell and B/B0 (azimuthal symmetry is assumed) for a given energy. The CRRESELE utility [uses these models] to calculate electron omnidirectional fluences (differential or integral) for 10 energy intervals (0.5-6.60 MeV). A user-specified orbit is traced through eight different outer zone electron flux models, at each energy, to provide an estimate of electron fluences received by a satellite under a wide range of magnetospheric conditions. Six of the eight CRRESELE models are parameterized by geomagnetic activity [using the Ap15 index], the seventh is simply a mission average, and the eighth is constructed from maximum flux values. Caution must be used when interpreting the results [of fluence calculations using the electron models] because CRRESELE is restricted to modeling the outer zone electrons [from L=2.5-6.8] and, consequently, excludes any electron fluence contributions from the inner zone and slot region."

Central to the construction of the CRRESELE electron models is the new geomagnetic activity index, Ap15, defined as follows in the CRRESELE Documentation:

> “For the purpose of constructing the [CRRESELE electron flux models] we define a new index derived from the Ap value. For a given day, the preceding 15 daily values of Ap are averaged to form the Ap15 index. The Ap15 index may be derived from either the estimated (NOAA-USAF Space Environment Services Center, Preliminary Report and Forecast of Solar Geophysical Data) or archived (NOAA World Data Center-A, Solar Geophysical and Prompt Reports) Ap values; the results agree within plus/minus 20% and display the same qualitative variations. A linear regression was performed of 455 days of estimated and archived indices and yielded the following linear relation: Ap15(estimated)= 0.8*Ap15(archived) + 2.6, with a correlation coefficient of 0.99. When Ap15 is referred to in this document, it is assumed that it is derived either directly from the weekly estimated Ap or indirectly (via the linear relationship given above) from the archived version of Ap.”

The CRRESELE science module is used to map the electron flux models used by CRRESELE into a three-dimensional grid specified by the user. A variety of magnetic field models can be used for the mapping. The eighty electron flux models used in CRRESELE were derived from the CRRES data as explained by the following excerpt from the CRRESELE Documentation,

> “The 0.512 second count rates [from each of the 10 energy channels of the HEEF instrument] are first binned by L (0.05 Re bins) and pitch angle (5 degree wide bins), folding the pitch angles > 90 degrees into the 0-90 degree quadrant. Various correction algorithms are next applied to these average count rates, which are then converted to average fluxes. For a given energy and L, the bin average pitch angle distributions are mapped to the magnetic equator [using the Olson-Pfitzer static external magnetic field model and the IGRF85 internal magnetic field model]. A database of daily average equatorial fluxes binned by day, energy, pitch angle, and L (2.5 <= L <= 6.55) is then created. [The data are then extrapolated to L=6.68 by using a linear least-squares fit to the data from L=6.0-6.55 for each equatorial pitch angle bin and energy channel.] This database is next sorted into eight models... Six of the eight models are parameterized by geomagnetic activity. The Ap15 index [described above] is determined for each day of the CRRES mission using NOAA’s weekly published values for the estimated daily planetary index (~Ap) (SESC, 1990-1991)... The lowest Ap15 values represent very quiet magnetospheric conditions, during which one can expect to find lower fluxes peaking at higher Ls. Likewise, the highest Ap15 values represent very active magnetospheric conditions, during which one can expect to find higher flux values peaking at lower L’s [*Brautigam et al.*, 1992]. [...] The range of Ap15 observed during the CRRES period (Ap15 = 6 to 55) is divided into six intervals (5-7.5, 7.5-10, 10-15, 15-20, 20-25, 25-55). The daily average flux database described above is then sorted according to the corresponding daily Ap15 value. [...] This procedure results in six electron equatorial flux models for each of the 10 energies. [...] Two additional models, independent of Ap15, are constructed from the same average flux database referred to above. For [the first additional model] the entire database is averaged together providing a mission averaged model. [The second additional model] is constructed from the maximum flux found at each L bin of the daily averages.”

After the user selects a flux model, the CRRESELE science module calculates the B/L coordinates for each grid point in the user-specified magnetic field model. The resulting flux is then obtained from the B/L coordinates and the chosen data file and then assigned to the grid

point. In this manner, a fully three-dimensional map of the outer zone flux data may be made from the CRRES data.

Note: Although AF-GEOSpace allows the data to be mapped in three dimensions using a variety of magnetic field models, the original CRRES data was binned into B/L coordinates using the IGRF85 magnetic field with the *Olson-Pfitzer* (1977) external field. The user should be aware that using other magnetic field models to map the data to three-dimensional space is inconsistent with the original reduction of the data.

CRRESELE Inputs

The CRRESELE science module requires the user to specify the following information to determine which data set to use and which magnetic field model to use in mapping the data,

B-Model: The magnetic field model used to convert from the B-L coordinates of the model to three-dimensional space. While the model used to reduce the CRRES data was *IGRF85/O-P*, the default setting uses *IGRF/O-P*. The *B-Model* options include:

- Dipole: A dipole field
- Dipole-Tilt: A tilted dipole field
- Dip-Tilt-Off: A tilted-offset dipole field
- IGRF: The International Geomagnetic Reference Field with no external contributions (Extrapolation beyond 2010).
- IGRF/O-P: The *IGRF* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.
- IGRF85: The International Geomagnetic Reference Field (1985) with no external contributions.
- IGRF85/O-P: The *IGRF85* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field. The original CRRES data was reduced using this option.

Note: The *IGRF85* internal field uses the Year, Day, and UT Global Parameters. Although less consistent with the original data reduction, models are computed significantly faster when one of the dipole field options is chosen.

Energy Channel (MeV):The energy channel parameter selects which of the ten flux models corresponding to the ten HEEF energy channels with central energies between 0.65 and 5.75 MeV is to be considered. The channel numbers and assigned limits are listed here. The $E_{central}$ column corresponds to the Energy Channel options shown in the Environment Window:

CH	E_{lower}	$E_{central}$	E_{upper}	ΔE
0	0.50	0.65	<0.80	0.30
1	0.85	0.95	<1.05	0.20
2	1.25	1.60	<1.70	0.45
3	1.70	2.00	<2.10	0.40

4	2.10	2.35	<2.50	0.40
5	2.50	2.75	<2.90	0.40
6	2.90	3.15	<3.30	0.40
7	3.30	3.75	<4.10	0.80
8	4.10	4.55	<4.95	0.85
9	4.95	5.75	<6.60	1.65

Ap15 Model Range: This parameter specifies which of the six flux model sets corresponding to the six geomagnetic activity levels (Ap15 = 5.0-7.5, 7.5-10.0, 10.0-15.0, 15.0-20.0, 20.0-25.0, or 25.0-55.0) is to be considered. Mission average (*AVE*) and mission maximum (*MAX*) model sets are also available.

Global Ap15: Pushing the *Compute* button causes an automatic calculation of the 15-day average of the Ap index (Ap15) based on the chosen global parameter set, i.e., from *Archive*, *Prelim*, or *Latest*, and displays the value in the window. If the parameter records are insufficient to compute Ap15 then the value will be labeled as missing.

CRRESELE Outputs

The CRRESELE science module returns a 3D Gridded Data Set of the electron flux for the selected energy channel and activity level (including *AVE* and *MAX*) in units of #/(cm^2 s keV). Note that the “model #” and “ch #” reported in the *Model Status* box correspond to the selected *Ap15 Model Range* and *Energy Channel (MeV)* values, respectively. For example, model #1 corresponds to *Ap15 Model Range* “Ap15 7.5-10.0” and ch #2 corresponds to *Energy Channel (MeV)* “0.95”.

The CRRESPRO Science Module

Model Name:	CRRESPRO
Version:	28 July 1994; IGRF updates 2009
Developer:	Air Force Research Laboratory and AER, Inc.
References:	Meffert, J.D., and M.S. Gussenhoven, CRRESPRO Documentation, *PL-TR-94-2218*, Phillips Laboratory, Hanscom AFB, MA (1994), ADA 284578
	Gussenhoven, M.S., E.G. Mullen, M.D. Violet, C. Hein, J. Bass, and D. Madden, CRRES High Energy Proton Flux Maps, *IEEE Trans. Nucl. Sci., 40*, 1450-1457 (1993)
	Olson, W.P., and K.A. Pfitzer, Magnetospheric Magnetic Field Modeling, Annual Scientific Report, Air Force Office of Scientific Research contract F44620-75-C-0033, McDonnell Douglas Astronautics Co., Huntington Beach, CA (1977), ADA 037492

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

CRRESPRO Overview

The CRRESPRO science and application modules are based on the PC program CRRES-PRO developed by the Air Force Research Laboratory. Note that the TPM-1 Science Module, described elsewhere in this document, is a low-altitude extension of the CRRESPRO model. A CRRESPRO Documentation excerpt:

> "CRRESPRO predicts proton omnidirectional fluence per year and integral omnidirectional fluence per year at selected energies in the range 1-100 MeV for an orbit specified by the user. It closely parallels its counterpart, CRRESRAD, which predicts dose behind four thicknesses of hemispherical aluminum shielding. [...] The CRRESPRO software uses flux models created from data collected by the proton telescope (PROTEL) on board the Combined Release and Radiation Effects Satellite (CRRES) flown from 25 July 1990 to 12 October 1991 during solar maximum. CRRES was in a geosynchronous transfer orbit with an inclination of 18 degrees, a perigee of 350 km, and an apogee of 33000 km. It traversed the radiation belts twice per orbit with a period of 9 hours 52 minutes. In March 1991, a magnetic storm caused a reconfiguration of the inner magnetosphere, resulting in, among other features, double proton belts forming over a certain energy range. Because of this change, two CRRES models were created. The quiet model uses data from July 1990 to March 1991, and the active model uses data from March 1991 to October 1991. Note that in this documentation and the CRRESPRO software, "quiet" refers to the period from July 1990 to March 1991 (single proton belt) and "active" refers to March 1991 to October 1991 (double proton belt). Quiet and active as used here for the inner radiation belt have no correspondence to quiet and active as determined by Kp. In fact, the average Kp for the two CRRES periods was the same, namely 2.2."

The CRRESPRO science module is used to map the proton flux data sets used by CRRESPRO onto a three-dimensional grid specified by the user. A variety of magnetic field models can be used for the mapping. Forty-four data sets were derived from the CRRES data as described by the following excerpt from the CRRESPRO documentation:

> "The flux models used by CRRESPRO are based on in situ flux measurements made by CRRES. [...] The instrument used to measure flux on CRRES was the proton telescope (PROTEL). PROTEL had two detector heads, which together measured protons from 1 to 100 MeV in 24 energy steps, giving a complete spectrum every 1.024 seconds. The angular resolution of the detector low (high) energy head was +/- 10 degrees by +/- 10 degrees (+/- 12 degrees by +/- 17 degrees). [...] For the CRRES proton models, a data base of differential number flux values on the magnetic equatorial plane was created using each PROTEL data point. The in situ values were mapped point by point to the magnetic equator conserving the first adiabatic invariant in the combined IGRF85 and Olson-Pfitzer quiet magnetic field model. The equatorial data were averaged by channel for each leg of each orbit in L shell bins of extent 1/20th Re and pitch angle bins of width 5 degrees. The equatorial data from all orbits occurring before (after) the March 1991 storm were then combined in the same L and pitch angle bins to create the CRRES quiet (active) proton model. [...] In summary, we have created two proton models from the CRRES PROTEL data base: a quiet model using data acquired before the March 1991 storm and an active model using data acquired after the storm. Each model potentially consists of twenty-four sub models, one for each energy channel. [...] We eliminate one of the 8.5 MeV channels and the 15.2 MeV channel [see full documentation for discussion]. This results in 44 different flux model files."

After selecting a proton data set, the module calculates the B/L coordinates for each grid point in the user-specified magnetic field model. Resulting flux values are then obtained from the B/L coordinates and the chosen data file and assigned to the grid point. In this manner, a fully three-dimensional map of the proton flux data may be made from the CRRES data.

Note: Although AF-GEOSpace allows the data to be mapped in three dimensions using a variety of magnetic field models, the original CRRES data was binned into B/L coordinates using the IGRF85 magnetic field with the *Olson and Pfitzer* (1977) external field. The user should be aware that using other magnetic field models to map the data to three-dimensional space is inconsistent with the original reduction of the data.

CRRESPRO Inputs

The CRRESPRO science module requires the user to specify the following information to determine which data set to use and which magnetic field model to use in mapping the data,

B-Model: The magnetic field model used to convert from the B-L coordinates of the model to three-dimensional space. While the model used to reduce the CRRES data was *IGRF85/O-P*, the default setting uses *IGRF/O-P*. The *B-Model* options include:

- Dipole: A dipole field
- Dipole-Tilt: A tilted dipole field

Dip-Tilt-Off: A tilted-offset dipole field

IGRF: The International Geomagnetic Reference Field with no external contributions (Extrapolation beyond 2010).

IGRF/O-P: The *IGRF* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.

IGRF85: The International Geomagnetic Reference Field (1985) with no external contributions.

IGRF85/O-P: The *IGRF85* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field. The original CRRES data was reduced using this option.

Note: The *IGRF85* internal field uses the Year, Day, and UT Global Parameters. Although less consistent with the original data reduction, models are computed significantly faster when one of the dipole field options is chosen.

Energy Channel (MeV): The energy channel parameter selects which of the proton flux data sets corresponding to the twenty-two PROTEL energy channels between 1 and 100 MeV is to be considered. The $E_{central}$ column corresponds to the Energy Channel options shown in the Environment Window:

CH	E_{lower}	$E_{central}$	E_{upper}	ΔE
1	1.1	1.5	1.9	0.8
2	1.9	2.1	2.3	0.4
3	2.3	2.5	2.7	0.4
4	2.7	2.9	3.1	0.4
5	3.1	4.3	5.5	2.4
6	5.5	5.7	5.9	0.4
7	5.9	6.8	7.7	1.8
8	7.7	8.5	9.3	1.6
9	9.3	9.7	10.1	0.8
10	10.1	10.7	11.3	1.2
11	11.3	13.2	15.1	3.8
12	15.1	19.4	23.7	8.6
13	23.7	26.3	28.9	5.2
14	28.9	30.9	32.9	4.0
15	32.9	36.3	40.2	7.3
16	40.2	41.1	43.2	3.0
17	43.2	47.0	50.8	7.6
18	50.8	55.0	59.2	8.4
19	59.2	65.7	72.2	13.0
20	72.2	81.3	90.4	18.2

Activity: The activity parameter specifies whether the *Quiet* (obtained before the 24 March 1991 storm) or *Active* (obtained after the 24 March 1991 storm) proton flux data sets are to be used.

CRRESPRO Outputs

The CRRESPRO Science module returns a 3D Gridded Data Set of the proton flux for the selected energy channel and activity level in units of #/(cm^2 s MeV).

The CRRESRAD Science Module

Model Name:	CRRESRAD
Version:	August 1992; IGRF updates 2009
Developer:	Air Force Research Laboratory and AER, Inc.
References:	Kearns, K.J., and M.S. Gussenhoven, CRRESRAD Documentation, *PL-TR-92-2201*, Phillips Laboratory, Hanscom AFB, MA (1992), ADA 256673
	Gussenhoven, M.S., E.G. Mullen, M. Sperry, K.J. Kerns, and J.B. Blake, The Effect of the March 1991 Storm on Accumulated Dose for Selected Satellite Orbits: CRRES Dose Models, *IEEE Trans. Nuc. Sci., 39*, 1765-1772 (1992)
	Gussenhoven, M.S., E.G. Mullen, D.H. Brautigam, E. Holeman, C. Jordan, F. Hanser, and B. Dichter, Preliminary Comparison of Dose Measurements on CRRES to NASA Model Predictions, *IEEE Trans. Nucl. Sci., 38*, 1655-1662 (1991)
	Olson, W.P., and K.A. Pfitzer, Magnetospheric Magnetic Field Modeling, Annual Scientific Report, Air Force Office of Scientific Research contract F44620-75-C-0033, McDonnell Douglas Astronautics Co., Huntington Beach, CA (1977), ADA 037492

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

CRRESRAD Overview

The CRRESRAD application is based on the PC program CRRESRAD developed and released by the Air Force Research Laboratory. A CRRESRAD Documentation excerpt:

> "CRRESRAD predicts the amount of radiation received in a specified orbit behind four hemispheres of aluminum with thicknesses of 82.5, 232.5, 457.5, and 886.5 mils. The prediction uses empirical models of accumulated dose measured on the Combined Release and Radiation Effects Satellite (CRRES) flown from 25 July 1990 to 12 October 1991 during solar maximum. CRRES was in a geosynchronous transfer orbit with an inclination of 18 degrees, a perigee of 350 km and an apogee of 33000 km. CRRES traversed the radiation belts twice per orbit with a period of 9 hours 52 minutes. The instrument used to measure accumulated dose is the CRRES Space Radiation Dosimeter which measures both dose rate and accumulated dose in four silicon detectors each of which is behind an aluminum dome of different thickness. The minimum energies required for particles to penetrate the domes and accumulate dose in the silicon detectors underneath are 20, 35, 50 and 75 MeV for protons and 1, 2.5, 5 and 10 MeV for electrons. Dose from particles depositing 0.05-1 MeV and 1-10 MeV is accumulated in two different channels called LOLET and HILET, respectively. HILET dose accumulates primarily from protons with energies of 20-100 MeV, but electrons with energies > 5

> MeV may contribute during large electron enhancement periods. LOLET dose accumulates from electrons, bremsstrahlung, and protons with energies > 100 MeV."

The CRRESRAD science module is used to map the radiation dose rate data sets from the CRRES mission onto a three-dimensional grid specified by the user. A variety of magnetic field models can be used for the mapping. Thirty-six data sets were derived from the CRRES data as described by the following excerpt from the CRRESRAD documentation:

> "The dose models used by CRRESRAD are based on in situ dose rate measurements made by CRRES. The instrument used to measure dose is the CRRES Space Radiation Dosimeter. [...] The dosimeter measured accumulated dose once every 4.096 seconds throughout the CRRES mission. The measured dose rates for each dome were binned by L shell and B/B0 to make average dose rate models in rads (Si) per second. The width of each bin in L shell is 1/20 Re, and the width of each bin in B/B0 is ~2 degrees latitude in a dipole field. The bins form a two dimensional array of 140 (L Shell) by 20 (B/B0) and cover L shells from 1 to 8 Re and magnetic latitudes of 0 degrees to ~40 degrees. The CRRES mission is divided into two parts. The magnetosphere is assumed to be in a quiet configuration before the March 1991 storm and in an active configuration after the March storm. A model was made separately for LOLET, HILET and LOLET+HILET for each of the four domes. Three sets of these models were made: one for quiet conditions before the storm (27 July 1990 to 19 March 1991), one for active conditions after the storm (31 March 1991 to 12 October 1991) and one for average conditions over the entire mission (27 July 1991 to 12 October 1991). These combinations result in 36 different dose rate models."

After the user selects which dataset is desired, the CRRESRAD science module calculates the B/L coordinates of each grid point from the user-specified magnetic field model. The resulting dose rate is then obtained from the B/L coordinates and the chosen data file. In this manner, a fully three-dimensional map of the dose rate data may be made from the CRRES data.

Note: Although AF-GEOSpace allows the data to be mapped in three-dimensions using a variety of magnetic field models, the original CRRES data was binned into B/L coordinates using the IGRF85 magnetic field with an *Olson and Pfitzer* (1977) external field. The user should be aware that using other magnetic field models to map the data to three-dimensional space is inconsistent with the original reduction of the data.

CRRESRAD Inputs

The CRRESRAD science module requires the user to specify the information to determine which data set to use and which magnetic field model to use in mapping the data,

B-Model: The magnetic field model used to convert from the B-L coordinates of the model to three-dimensional space. While the model used to reduce the CRRES data was *IGRF85/O-P*, the default setting uses *IGRF/O-P*. The *B-Model* options include:

- Dipole: A dipole field
- Dipole-Tilt: A tilted dipole field

Dip-Tilt-Off:	A tilted-offset dipole field
IGRF:	The International Geomagnetic Reference Field with no external contributions (Extrapolation beyond 2010).
IGRF/O-P:	The *IGRF* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.
IGRF85:	The International Geomagnetic Reference Field (1985) with no external contributions.
IGRF85/O-P:	The *IGRF85* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field. The original CRRES data was reduced using this option.

Shielding: The shielding parameter specifies whether the *82.5, 232.5, 457.5* or *886.5 mil* aluminum hemisphere shielding thickness data set is to be used.

Channel: The channel parameter specifies which dose rate data set is to be used:

LoLet:	(0.05-1 MeV deposited from electrons, bremsstrahlung, and > 100 MeV protons)
Hi/Lo Let:	(0.05-10 MeV deposited) = *LoLet* + *HiLet*
HiLet:	(1-10 MeV deposited from 20 - 100 MeV protons and > 5 MeV electrons during large enhancement periods)

Activity: The activity parameter specifies whether the *Quiet* (obtained before the 24 March 1991 storm), *Active* (obtained after the 24 March 1991 storm), or *Average* (average of the *Active* and *Quiet* intervals) dose rate data sets are to be used.

CRRESRAD Outputs

The CRRESRAD science module returns a 3D Gridded Data Set of the dose rate in units of rads (Si) per second for the selected shielding level and detector combination.

The CUTOFF Science Module

Model Name: Geomagnetic Vertical Cutoff Rigidity Interpolation Model

Version: 30 September 2005 (Version 4.03)

Developer: D.F. Smart and M.A. Shea, Air Force Research Laboratory

References:

Flückiger, E.O., and Kobel, E., Aspects of Combining Models of the Earth's Internal and External Magnetic Field, *J. Geomag. Geoelectr., 42*, 1123 (1990)

Kahler, S., and A. Ling, Comparisons of High Latitude E > 20 MeV Proton Geomagnetic Cutoff Observations with Predictions of the SEPTR Model, *Annales Geophysicae, 20*, 997-1005 (2002)

Sabaka, T.J., Langel, R.L., Baldwin, J.A., and Conrad, J.A., The Geomagnetic Field 1900-1995, Including the Large-Scale Field from Magnetospheric Sources, and the NASA Candidate Models for the 1995 Revision of the IGRF, *J. Geomag. Geoelect., 49*, 157 (1997)

Shea, M.A., Smart, D.F., and McCracken, K.G., A Study of vertical Cutoff Rigidities Using Sixth degree simulations of the Geomagnetic Field, *J. Geophys. Res., 70*, 4117-4130 (1965)

Shea, M.A., and Flückiger, E.O., Magnetospheric Models and Trajectory Calculations, *Space Science Reviews*, *93*, 305-333 (2000)

Smart, D.F., and Shea, M.A., Geomagnetic Cutoffs: a Review for Space Dosimetry Applications, *Adv. Space Res., 14(10),* 787-796 (1994)

Smart, D.F., and Shea, M.A., World Grid of Cosmic Ray Vertical Cutoff Rigidities for Epoch 1990.0, *Proc. Int. Cosmic Ray Conf. 25th*, *2*, 401-404 (1997a)

Smart, D.F., and Shea, M.A., Calculated Cosmic Ray Cutoff Rigidities at 450 km for Epoch 1990.0, *Proc. Int. Cosmic Ray Conf. 25th*, *2*, 397-400 (1997b)

Smart, D.F, Shea, M.A., and Flückiger, E.O., Calculated Vertical Cutoff Rigidities for the International Space Station during Magnetically Quiet Times, *Proc. Int. Cosmic Ray Conf. 26th*, *7*, 394-397 (1999a)

Smart, D.F., Shea, M.A., Flückiger, E.O., Tylka, A.J., and Boberg, P.R., Calculated Vertical Cutoff Rigidities for the International Space Station during Magnetically Active Times, *Proc. Int. Cosmic Ray Conf. 26th*, *7*, 398-401 (1999b)

Smart, D.F., Shea, M.A., Flückiger, E.O., Tylka, A.J., and Boberg, P.R., Changes in Calculated Vertical Cutoff Rigidities at the Altitude of the International Space Station as a Function of Magnetically Activity, *Proc. Int. Cosmic Ray Conf. 26th, 7*, 337-340 (1999c)

Smart, D.F., and Shea, M.A., A Comparison of the Tsyganenko Model Predicted and Measured Geomagnetic Cutoff Latitudes, *Adv. Space Res., 28(12)*, 1733-1738 (2001)

Smart, D.F., and Shea, M.A., The Space-Developed Dynamic Vertical Cutoff Rigidity Model and Its Applicability to Aircraft Radiation Dose, *Adv. Space Res., 32(1),* 103-108 (2003)

Smart, D.F., M.A. Shea, A.J. Tylka, and P.R. Boberg, A Geomagnetic Cutoff Rigidity Interpolation Tool: Accuracy Verification and Application to Space Weather, *Adv. Space Res., 37,* 1206-1217 (2006)

Tsyganenko, N.A., A Magnetospheric Field Model with a Warped Tail Current Sheet, *Planetary Space Sci., 37*, 5-20 (1989)

Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

CUTOFF Overview

The CUTOFF science module accesses the Geomagnetic Vertical Cutoff Rigidity Interpolation Model to generate cutoff rigidity values for any altitude from in the earth's atmosphere (≥ 20 km) to beyond geosynchronous orbit. The magnetic rigidity of a particle is a measure of its resistance to a magnetic field that deflects it from a straight-line trajectory. Specifically, rigidity R = pc/q where p is the particle momentum, c is the speed of light, and q is the particle charge. Generally, particles with higher rigidities are more likely to gain access to a given location inside the magnetosphere. Typically, at a given location there is an upper cutoff rigidity value (above which all rigidities are allowed, and a lower cutoff rigidity value (below which all rigidities are forbidden). Between the upper cutoff and the lower cutoff there is an alternating series of allowed and forbidden trajectories called the cosmic ray penumbra which is both rigidity and magnetic activity dependent. Owing to penumbral transparency, an "effective cutoff rigidity" value is also determined. Geomagnetic cutoffs also depend on particle direction with the maximum geomagnetic cutoff in the magnetic east direction (90° from the zenith) and the minimum geomagnetic cutoff in the magnetic west direction (90° from the zenith). The geomagnetic cutoffs in the north and south magnetic planes are approximately equal to the cutoff in the vertical (zenith) direction. For convenience, the geomagnetic cutoff values are provided both in terms of rigidity [in GV] and proton energy [in MeV]. Modeled and measured cutoffs at 620 km exhibit the same general trend, however, measured cutoffs were about one degree in latitude equatorward of those modeled during magnetically active times [*Smart and Shea*, 2001]. Extending down into the atmosphere, cutoff rigidity model output used for computing aircraft radiation dose resulted in good agreement during the high-energy solar cosmic ray event of 24 October 1982 [*Smart and Shea*, 2003]. The following is a summary of the procedure used to determine the cutoff rigidity model quantities within AF-GEOSpace.

Background: *Smart et al.* [1999c] performed basic geomagnetic vertical cutoff rigidity calculations using proton trajectory-tracings initiated from 450 km altitude on a 5° x 5° world grid for specified levels of magnetic activity quantified by integer *Kp* value and quantized Universal time (0000, 0600, 1200, and 1800 hours UT). Please note that the previous release, AF-GEOSpace V2.1, contained CUTOFF Version 4.01 of 3 June 2003.

For this version of the model, these calculations were performed using quantized Universal time every three hours (0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 hours UT) [see *Smart et al.*, 2006]. Orbits of particles with specific rigidity values were traced backwards to determine if access from space was allowed or forbidden at each location. Penumbral transparency, a value from between 0 and 1, is the fraction of allowed rigidities as determined by going through the penumbra in steps of 0.01 GV. The effective cutoff rigidity within the penumbra is then determined by subtracting the transparent fraction of the penumbra from the upper cutoff rigidity value [*Shea et al.*, 1965]. The magnetospheric magnetic field was defined for 1 January 1995 and used the IGRF 1995 internal field [*Sabaka et al.,* 1997] and the *Tsyganenko* [1989] magnetospheric model as combined by *Flückiger and Kobel* [1990]. Because the *Tsyganenko* [1989] model only describes magnetospheric configurations for *Kp* indices of 0 to 5, the *Boberg* [1995] extension was used in increments of -100 nT to include *Dst* effects to represent probable conditions for Kp 6 through 9 and "10". For example, the Kp = 7 configuration is represented by the *Tsyganenko* [1989] Kp = 5 model plus a -200 nT ring current extension. See *Smart et al.*, [1999a, 1999b, 1999c, 2000, 2006] for more details on the geomagnetic cutoff rigidity determinations and the trajectory tracing processes. The results of these calculations are archived within AF-GEOSpace for use in the general interpolation procedure described below.

Interpolation Method: The McIlwain "L" parameter can be utilized in the cutoff equation for the cosine squared of the magnetic latitude such that the vertical cutoff rigidity equation used has the form:

$$R = V(k)/ L^2$$

with V(k) being a constant in the cutoff rigidity equation that varies with grid location, i.e., latitude and longitude (see *Smart and Shea* [1994]). First, a linear interpolation uses the V(k) values and associated L values at 450 km from the nearest 4 points in the 5° x 5° world grid to determine the cutoff rigidity R at the satellites latitude, longitude and an altitude of 450 km. Multiplying the interpolated R value by L^2 (using the L appropriate for the satellite's latitude, longitude, and a 450 km altitude) produces the V(k) constant appropriate for the satellite location. This V(k) is then combined with the satellite's actual L value in the above equation to produce an extrapolated vertical geomagnetic cutoff rigidity for the satellite's position. After the vertical cutoff rigidity is determined, Störmer theory is used to translate to cutoff values at 90 degrees east and 90 degrees west. The Störmer equation (valid in a magnetic dipole configuration) can be written in the form:

$$R_\alpha = 4R \ \{[\ 1 + (1 - \sin\boldsymbol{\varepsilon} \sin\boldsymbol{\varphi} \cos^3\lambda)^{1/2}]^2 \ \}$$

In this equation R_α is the cutoff rigidity in a specific angular direction, R is the vertical cutoff rigidity, λ is an appropriate magnetic latitude, ε is the angle from the zenith direction, and φ is the azimuth angle measured clockwise from magnetic north. Owing to discrepancies arising between invariant and magnetic latitude at high altitudes, the corrected geomagnetic latitude is also calculated and used above for λ if it is smaller than the invariant latitude $\Lambda = \mathrm{acos}(L^{-1/2})$. As noted above, the angular geomagnetic cutoffs are lowest from the magnetic west and highest from the magnetic east while the cutoffs in the magnetic north and south directions are the same as the vertical cutoff.

CUTOFF Inputs

The CUTOFF science module requires the Global Parameters Year, Day, UT, and Kp (SSN, F10.7 and Ap are not used). The Kp index has 28 defined values, i.e., {0, 0^+, 1^-, 1, 1^+, 2^-, 2, 2^+, 3^-, 3, 3^+, 4^-, 4, 4^+, 5^-, 5, 5^+, 6^-, 6, 6^+, 7^-, 7, 7^+, 8^-, 8, 8^+, 9^-, 9}. The decimal equivalents from the Global data set represent a Kp index of 0 with 0.0, 0^+ with 0.3, 1^- with 0.7, 1 with 1.0, 1^+ with 1.3, 2^- with 1.7, 2 with 2.0, 2^+ with 2.3, etc. Note that there is no Kp = 0^- or 9^+. The CUTOFF module utilizes 10 Kp-dependent coefficient sets with a different set for each Kp integer-based grouping such as Kp = {2-, 2, or 2+}. For manual entry in the AF-GEOSpace Global text field, the same Kp = "2" coefficient set, for example, can be accessed if the decimal index is in the range $1.60 < Kp \leq 2.60$. Note that while the model authors provide sets of coefficients to represent the extreme Kp = 9 and "Kp=10" conditions, these sets are not presently accessible with AF-GEOSpace owing to fixed input restrictions on the input Global Kp. Note that the model determines output by interpolating tabulated rigidity and proton cutoff values stored at spatial intervals of 5 degrees in latitude by 5 degree in longitude. The default Grid Tool uses 37 latitude and 73 longitude grid points to match this resolution. Note: 20 km is the lowest radial input, i.e., the top of the atmosphere, so any lower number will be assigned the 20 km result.

CUTOFF Outputs

The CUTOFF science module returns a 3D Gridded Data Set of the following quantities:

L	McIlwain L coordinate (Earth radii)
InvLt	Invariant or corrected geomagnetic latitude (degrees)
PTV	Penumbral transparency at this cutoff rigidity
RLGVPV	Lower cutoff rigidity (GV) in the vertical direction.
RUGVPV	Upper cutoff rigidity (GV) in the vertical direction.
RCGVPV	Effective cutoff rigidity (GV) in the vertical direction.
RLGVPE	Lower cutoff rigidity (GV) in the 90° East direction.
RUGVPE	Upper cutoff rigidity (GV) in the 90° East direction.
RCGVPE	Effective cutoff rigidity (GV) in the 90° East direction.
RLGVPW	Lower cutoff rigidity (GV) in the 90° West direction.
RUGVPW	Upper cutoff rigidity (GV) in the 90° West direction.
RCGVPW	Effective cutoff rigidity (GV) in the 90° West direction.
EPNRLV	Lower proton cutoff (MeV) in the vertical direction.
EPNRUV	Upper proton cutoff (MeV) in the vertical direction.
EPNRCV	Effective proton cutoff (MeV) in the vertical direction.
EPNRLE	Lower proton cutoff (MeV) in the 90° East direction.
EPNRUE	Upper proton cutoff (MeV) in the 90° East direction.
EPNRCE	Effective proton cutoff (MeV) in the 90° East direction.
EPNRLW	Lower proton cutoff (MeV) in the 90° West direction.
EPNRUW	Upper proton cutoff (MeV) in the 90° West direction.
EPNRCW	Effective proton cutoff (MeV) in the 90° West direction.

We recommend displaying output in 2D or 3D plots using the COORD-SLICE graphical object or examining output along an orbit by running the SATEL-APP application followed by the ORBIT-PROBE graphical object.

The GCPM Science Module

Model Name:	Global Core Plasma Model
Version:	Version 2.4 of 19 June 2009 based on *Gallagher et al.* [2000]
Developer:	D.L. Gallagher, NASA Marshall Space Flight Center, Huntsville, AL (Code source- http://plasmasphere.nasa.gov/models/)
References:	D. Bilitza and Reinisch, B., International Reference Ionosphere 2007: Improvements and new parameters, *J. Adv. Space Res., 42, #4*, 599-609, doi:10.1016/j.asr.2007.07.048 (2008)
	Gallagher, D., P. Craven, and R. Comfort, Global core plasma model, *J. Geophys. Res., 105(A8)*, 18819-18833 (2000).

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

GCPM Overview

The Global Core Plasma Model (GCPM) of *Gallagher et al.* [2000] is an empirical description of thermal plasma densities (e-, H^+, He^+, and O^+) in the plasmasphere, plasmapause, magnetospheric trough, and polar cap. The authors note that GCPM is intended to provide representative thermal plasma densities in these regions, but is not intended to represent the distribution of thermal plasma density at any given time. GCPM-2008 uses the Kp index and is coupled to the International Reference Ionosphere [*Bilitza and Reinisch*, 2008] in the transition region 500-600 km (see IRI2007 Science Module section for details) which requires additional input quantities provided in data files.

GCPM Inputs

Note: Valid run times are limited by the content of file *ig_rz.dat* described below.

Global Parameters: Year, Day, UT, and Kp

(SSN is not required)

F10.7 and *Ap* are required for IRI2007, but the values entered in the *Globals* section are ignored. *F10.7* and *Ap* are read directly from file $AFGS_HOME/models/data/IRI2007/ap.dat. File updates are made available periodically via FTP (http://iri.gsfc.nasa.gov/).

Required Data files: IRI2007 retrieves all input quantities (except for the time) from data files found in folder $AFGS_HOME/models/data/IRI2007, namely

dgrf##.dat, igrf05.dat, igrf05s.dat: Definitive IGRF and IGRF coefficients for the years 1945-2010 (## = two-digit year)

URSI##.asc: Coefficient files for the URSI model (## = month + 10)

ig_rz.dat:	File contains (1) the ionospheric index (IG12) based on foF2 measurements from a dozen ionosondes correlated with CCIR foF2 maps [*Liu et al.,* 1983] and (2) the 12-month running mean of sunspot number (Rz12) for 1958 thru 2012. If a date outside this range is used, no valid output can be generated owing to lack of inputs for the IRI2007 model. File updates are made available periodically via FTP at http://iri.gsfc.nasa.gov/.
ap.dat:	Contains 3-hour *Ap* magnetic index and F10.7 daily index from 1958 thru 30 April 2010. If a date outside this range is used, then the *Ap*-dependent "foF2 storm model" [*Fuller-Rowell et al.*, 2000; *Araujo-Pradere et al.,* 2002] will be turned off within the IRI2007 model. File updates available periodically via FTP at http://iri.gsfc.nasa.gov/.

GCPM Outputs

The GCPM Science Module returns 3D Gridded data sets of total density (#/cm^3) of electrons, hydrogen (H^+), helium (He^+), and oxygen (O^+). Best viewed by checking the *Log10* box within of the Data Map Graphical Option.

The IONSCINT Science Module (V2.5.1 Only)

Model Name:	High Fidelity Ionospheric Scintillation Simulation Algorithm (IONSCINT)
Version:	2.00 (13 March 2000)
Developer:	Radex, Inc. (now AER, Inc.) and the Air Force Research Laboratory
Sponsor:	Air and Space Natural Environment, Modeling and Simulation Executive Agent (ASNE MSEA), Ashville, NC
References:	Secan, J.A., and R.M. Bussey, An Improved Model of High-Latitude F-Region Scintillation (WBMOD Version 13), *PL-TR-94-2254* (1994), ADA 288558

Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

IONSCINT Overview

The High Fidelity Ionospheric Scintillation Simulation Algorithm (IONSCINT) provides realistic scenarios of disruptions in trans-ionospheric radio wave communications with spacecraft due to equatorial scintillation. The resulting signal fades encountered by ground-to-satellite links are due to instabilities in the ionospheric F-region related to spread-F plumes that develop after sunset when conditions are favorable. This module addresses only satellites positioned in geosynchronous orbit and is limited to a frequency of 244 MHz. While scintillation can occur in both amplitude and phase, IONSCINT treats only the intensity (or amplitude) scintillation.

This excerpt from the user's manual[1] contains more background and description:

> "Prior to the development of IONSCINT, the only tools available for the prediction of scintillation for simulation purposes were statistical (climatological) models, most notably the Wide Band model (WBMOD). Although expressing the seasonal, daily and solar cycle variability of equatorial scintillations *on average*, these models did not allow for the introduction of day-to-day variability in scintillation, even in an average sense. Since equatorial scintillations are in fact *extremely* variable from day-to-day at a given location, simulation results based only on the average scintillation levels were necessarily lacking in a critical feature of the spread-F phenomenon itself. The IONSCINT program was developed to overcome the limitations of climatological models for simulations by reproducing *both* the climatological and the day-to-day variability of equatorial scintillations, thereby producing a simulation result [that] is much more in line with actual expected conditions for any particular simulation scenario.
>
> IONSCINT generates simulated scintillation results by "replaying" measured scintillation scenarios for a specified season and set of geophysical conditions, drawing on nightly data measured over [the four years prior to 2000] in the South America sector. These

[1] User's Guide for the High Fidelity Ionospheric Scintillation Simulation Algorithm, Prepared for AFRL/VSB by Radex, Inc., March 8 (2000)

nightly measured scenarios are used to drive a model for spread-*F* plume development and evolution that was developed as part of the Scintillation Network Decision Aid (SCINDA) model, from extensive experience with scintillation data. The scenarios are selected pseudo-randomly to conform to the correct average seasonal behavior yet preserve the day-to-day variability. The South America data set is extrapolated to arbitrary positions on the Earth through the use of average climatology predictions (WBMOD). The basic result is a simulated prediction of scintillation intensity throughout a specified time of day and year and under specified geophysical conditions. The result is suitable for the production of geographic maps of satellite outages".

IONSCINT Inputs

The IONSCINT science module requires the following inputs,

Global Parameters: Year, Day, UT, Kp, and SSN (F10.7 and Ap are not used).

Random Number Seed: A negative integer (magnitude < 30,000) used to select from among 51 scintillation scenarios available to the model. Using the same input seed will cause the same sequence of scintillation scenarios to be generated. To recreate the same scenario for more than one satellite, perform additional separate IONSCINT runs using the same *Random Number Seed* for each satellite (as defined by its *Satellite Longitude*, see below).

Theater: The following geographic latitude and longitude values define the theater over which scintillation conditions will be computed. Theater width is limited to a maximum of 90°.

Lat 1: Southern boundary of the theater in geocentric latitude in degrees.

Lat 2: Northern boundary of the theater in geocentric latitude in degrees.

Lon 1: Western boundary of the theater in geocentric East longitude in degrees.

Lon 2: Eastern boundary of the theater in geocentric East longitude in degrees.

Note: The *Grid Tool* is not active for the IONSCINT science module. The calculation is performed using a fixed resolution geographical grid (1° x 1°) defined by the integer values of the Theater latitude and longitude boundaries given above. The scintillation climatology produced in the simulation is representative of the seasonal behavior at the mid-point of the chosen theater.

Satellite Longitude: Geographic longitude (degrees East) of the geosynchronous satellite (geographic latitude is internally fixed equal to zero degrees).

Sunspot Number and KP: The sunspot number and geomagnetic activity level may be provided to IONSCINT in the following two ways,

Globals: IONSCINT will obtain SSN and Kp from the global parameter values available to AF-GEOSpace. For static

runs, these parameters appear in the text boxes at the top of the environment window. For dynamic runs, the SSN and Kp values to be used are listed in the dynamics global parameter list viewable by accessing the *Globals* menu and selecting the *Show* option. Both sources can be edited directly by the user.

Constant: IONSCINT will use constant SSN and Kp values that the user provides by editing the following two text boxes directly in the IONSCINT Options window.

SSN: Sunspot number (see note below)

Kp: Geomagnetic activity index (values 0.00 to 9.00)

Note: The SSN values provided by AF-GEOSpace are identical to the daily values archived by NGDC. The IONSCINT authors note that the daily sunspot number is not well correlated with scintillation and that the preferred sunspot number to use should represent the smoothed ~90-day average of the daily values, e.g., it will suffice to choose a value representative of the position in the solar cycle. The authors suggest, for example, using SSN = 10 to represent solar minimum, SSN = 50 to represent the ramp up or down from solar maximum, and SSN = 100 and 150 to represent "low-activity" and "high-activity" solar maximum values, respectively.

Operational Mode: IONSCINT output can be calculated using two different methods,

Plume: IONSCINT produces scintillation output based on day-to-day measurements such that scintillation at a given time of day and location differs substantially from day to day. This mode incorporates realistic statistical "random" variations in the scintillation.

Climo: IONSCINT produces scintillation output made with the average scintillation model WBMOD. For details, see the WBMOD Science Module section of this document.

For both the *Plume* and *Climo* methods, two parameters must be specified.

Scintillation Intensity: This specifies the desired scintillation intensity (0.00 to 1.00). The scintillation intensity should typically be set to ~0.5 when in the *Plume* mode. For *Climo* mode (when WBMOD results are utilized) a value of 0.5 tends to give rather weak results so it is suggested that a value ~0.90 be used. This will result in the evaluation of the WBMOD climatology at the 90th percentile level as is quite commonly done for prediction purposes.

Percentile for S4 to dB fade: This specifies the percentile (0 to 100) used to produce the dB fade corresponding to each S4 value produced in the output, e.g., if 0.95 is specified, then the dB fade value will correspond to the fade level of

the top 5% of all fades corresponding to each S4. The parameter is also known as the Nakagami percentile.

IONSCINT Outputs

The IONSCINT science module returns 2D Gridded Data Sets representing the scintillation parameters on a 1° x 1° geographic coordinate grid. We recommend displaying output in 2D plots using the COORD-SLICE graphical object. AF-GEOSpace will then display a spatial distribution (map) for the following parameters:

S4Index: The S4 scintillation index, a normalized standard deviation of the signal intensity (dimensionless). It is common to refer to scintillation threshold levels of 0.3 and 0.6 as "yellow" and "red" to indicate interference and outage, respectively.

dBfade: The dB fade depth of the signal intensity (decibels). It is directly related to the *S4Index* through the selection of the *Percentile for S4 to dB Fade* input parameter. For a given value of *S4Index*, the value of *dBfade* increases as the value of *Percentile for S4 to dB Fade* increases.

ProbCom: The probability of communication breakdown is a value between zero and 100% indicating the probability of communications problems. This is defined as zero when *S4Index* is below 0.3 ("yellow" threshold) and as 100% when *S4Index* is greater than 0.6 ("red" threshold). Note that it is therefore possible to have non-zero *S4Index* and *dBfade* values with no communications problems indicated.

SatElev: The elevation angle (degrees) of the satellite as measured from locations within the defined theater, i.e., equal to 90 degrees when satellite is directly overhead.

The IONSCINT-G Science Module

Model Name:	GPS Version of the High Fidelity Ionospheric Scintillation Simulation Algorithm (IONSCINT-G)
Version:	July 2009
Developer:	AER, Inc. and the Air Force Research Laboratory
References:	Secan, J.A., and R.M. Bussey, An Improved Model of High-Latitude F-Region Scintillation (WBMOD Version 13), *PL-TR-94-2254* (1994), ADA 288558
	Steenburgh, R.A., C.G. Smithtro, and K.M. Groves, Ionospheric scintillation effects on single frequency GPS, *Space Weather, 6*, S04D02, doi:10.1029/2007SW000340 (2008)

Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

IONSCINT-G Overview

The IONSCINT-G Science Module is a simulation tool for producing realistic scenarios of disruptions in trans-ionospheric radio communications at GPS frequencies between spacecraft and stationary platforms. It is based on the model "The GPS Version of the High Fidelity Ionospheric Scintillation Simulation Algorithm (IONSCINT-G)." Given a time interval, a selection of scintillation database options related to solar activity conditions, a random number seed, and a platform position, the IONSCINT-G Science Module can produce a time series of skymaps showing S4 scintillation as a function of azimuth and elevation angle as measured from the platform position. The scintillation scenarios are selected at random from data taken from a fixed L-Band link over various years (1997 – 2001). The following background information is excerpted from the IONSCINT-G user's manual[2].

> "Equatorial scintillation exhibits pseudo-random elements in that it is composed of discrete "plumes" which stretch along magnetic field lines rather predictably, but vary in longitudinal extent in an unpredictable manner. Scintillation, especially at GPS frequencies, can best be thought of as an on-again, off-again process when viewed from a fixed point on the Earth, with a time scale of perhaps an hour. The occurrence of scintillation on a night-to-night basis is also difficult to predict. Although there are times of the year for various longitude sectors during which scintillation is nearly absent, it is typical for a night with no scintillation in a particular region to follow a night of strong scintillation. This makes "average" climatological scintillation models (WBMOD) difficult to incorporate into realistic simulations of scintillation impact on receivers.
>
> The IONSCINT-G program addresses this need by incorporating the random nature of scintillation into the production of nightly scintillation scenarios, which are constrained by geomagnetic latitude, solar cycle, and time of year. The scenarios are generated by piecing together nightly measurements of scintillation from a fixed ground-to-satellite

[2] User's Manual for the GPS Version of the High Fidelity Ionospheric Scintillation Simulation Program (IONSCINT-G), Version 1.0, Prepared for AFRL/VSB by Radex, Inc., June (2002)

link at GPS frequencies to form a global picture of scintillation which contains the discrete "plumes" which are characteristic of actual nightly scintillation, as opposed to the time-averaged probabilities which would be obtained from climatological modeling.

The IONSCINT-G representation of scintillation in a theater, consisting of regions of high intensity separated by regions of no scintillation, is especially important for GPS navigation investigations where the number of satellites effected and their positions are the critical issue. However, this improved realism comes with a price which, For IONSCINT-G, is the fact that a single run cannot be used to assess overall impact. Rather, a run of the software represents what might be expected on a single day. It is entirely possible, for example, for a run to produce no significant scintillation for a given platform and night, even at the height of scintillation season and at solar maximum. Therefore, multiple runs for the system with subsequent analysis must be used to assess possible impacts. Worst case scenarios are built into IONSCINT-G to aid in this evaluation."

IONSCINT-G Inputs

The IONSCINT-G Science Module requires four types of inputs used to define (1) a static run time or dynamic run time interval, (2) scintillation database options to characterize the type of scenario desired along with a large random number seed (typically a 5-digit number), (3) the static platform position, and (4) the resolution in azimuth and elevation of the S4 scintillation skymap to be created representing the view from the user-specified platform. Specifically, the following inputs are required.

Global Parameters: Year, Day, UT (Kp, SSN, F10.7, and Ap are not used).

Scintillation Database Options: Scenarios are generated from the scintillation database using an input solar activity level and four related selection modifiers, namely

Sunspot Activity Level: Scintillation scenarios corresponding to four different levels of solar activity as defined by sunspot number (SSN) are represented. It should be noted that no significant scintillation at GPS frequencies occurs at solar minimum and "worst case" scenarios are associated with maximum SSN values.

1 = Low (10-30): This SSN range represents solar minimum conditions.

2 = Moderate (50-75): This SSN range represents conditions during the ramp up or down from solar maximum.

3 = High (85-100): This SSN range represents conditions from a "low-activity" maximum.

4 = Maximum (100-120): This SSN range represents conditions from a "high-activity" maximum.

Use Seasonal Climatology: This option provides the most realistic representation of the seasonal dependence of

scintillation as a function of longitude. If the occurrence of scintillation is desired at all longitudes regardless of scintillation season, then uncheck this option. Note that quiet scintillation-free nights can still occur even with this option unchecked.

Use Only Top 10% Scintillation Scenarios: Selecting this option highlights the “worst” of the possible scenarios, i.e., it restricts scenario selection to be made randomly from only those portions of the database representing the top 10% of nights based on the total time of active scintillation per night. If left unchecked, then scenario sets will be chosen randomly from all in-season nights for the chosen solar activity level.

Retain Generated Random Number Seed Between Runs: Each time a new IONSCINT-G entry appears in the Active Modules list, e.g., *SciIonScintg0*, a new random number is placed in the text box to the right of the next input line. Each run utilizes the random number seed that is visible **before** the run is made. This value is used to randomize the selection of scenario sets from the appropriate solar activity level section of the database. For a given set of activity settings, using the same number seed will cause the same scintillation scenario to be generated. Select this option to retain use of the random number seed for additional runs. If neither this nor the next option is checked, then a *Run/Update* will place a new random number seed in the text box (to be used for the next run!). If you complete a run without checking this option and did not record the number seed, you can recover the value used in your last run from file *C:\TEMP\SciIonScintg#\IONSCINTG.OUT* (assuming default scratch directory C:\TEMP).

Specify and Retain Random Number Seed: Select this option and edit the number seed value in the text box to retain use of the number seed for the current and future runs. Using the same input seed will cause the same scintillation scenario to be generated. To recreate the same scenario for more than one *Platform Position*, perform additional IONSCINT-G Science Module runs using the same *Random Number Seed* for each platform location.

Platform Position: The Platform Position defines the fixed reference position used for all GPS scintillation scenario calculations. Note that there will be no scintillation directly overhead (i.e., at the center of the skymap viewed with the IONSCINT-G graphic module) if the platform is placed at a

magnetic latitude poleward of 30 degrees. The location is input in geographic coordinates assuming a spherical Earth, namely

Latitude: The platform's North latitude in degrees.

Longitude: The platform's East longitude in degrees (0-360).

Altitude (km): The platform's altitude in kilometers above the Earth's surface.

S4 Skymap Output Resolution: For a given *Platform Position*, the following settings control the skymap output resolution in azimuth and elevation.

Delta Azimuth(Deg): Degrees per step in azimuth. Permitted input range is 1.0 to 36.0 and the value will be adjusted internally to create an integer number of steps.

Delta Sin(Elevation): Elevation step size expressed in units of sin(elevation). Permitted input range is 0.01 to 0.10 and the value will be adjusted internally to create an integer number of steps.

Notes: (1) The *Data Tool* and *Grid Tool* are not active for the IONSCINT-G science module. The calculation is performed using the grid defined in the *S4 Skymap Output Resolution* section defined above. However, *Data Probes* available via the IONSCINT-G Graphical Module can be used to view details in S4 as a function of fixed azimuth and elevation in 1-D viewports

(2) The *File* menu *Save Model/Open Model* features work only when the *Retain Generated Random Number Seed Between Runs* or *Specify and Retain Random Number Seed* option has been used.

IONSCINT-G Outputs

The IONSCINT-G science module returns 2D Gridded Data Sets with the S4 scintillation parameter for plotting in skymaps representing the view (in azimuth and elevation) from a stationary platform position. The S4 scintillation index is a normalized standard deviation of the signal intensity (dimensionless). S4 index skymaps can be viewed in *Spectral* viewports using the IONSCINT-G Graphical Module. To prepare an active graphics window for viewing the S4 scintillation skymaps, use the *Viewport* menu to select *Spectral* under the *Projection* option. Note that the IONSCINT-G Graphical Module also provides data probes for viewing the S4 parameter as a function of fixed azimuth and elevation values in 1-D viewports.

Hint: To produce realistic S4 scintillation time profiles for a given platform-satellite link, this science module should be run in dynamic mode for a time period using a fixed *Platform Position* with a variety of *Scintillation Database Options* settings. The user should examine the resulting skymap sequences to select a suitable S4 scenario and then run the IONSCINT-G Application Module using the IONSCINT-G Science Module input settings for that scenario along with those of the satellite of interest. This will enable the generation of 1D plots of the S4 scintillation index vs. time for the desired platform-satellite link.

The IRI2007 Science Module

Model Name: International Reference Ionosphere (IRI) Model 2007

Version: May 2007

Developer: IRI is sponsored by the Committee on Space Research (COSPAR) and the Union Radio Scientifique Internationale (URSI). Code provided by NASA's Space Physics Data Facility and the National Space Science Data Center via FTP (http://iri.gsfc.nasa.gov/).

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Truhlik, V., L. Triskova, and J. Smilauer, An empirical topside electron density model for calculation of absolute ion densities in IRI, *Adv. Space Res., 71(5)*, 928-934 (2006)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

IRI2007 Overview

The IRI2007 Science Module utilizes the International Reference Ionosphere (IRI) model of 2007, an empirical model specifying monthly averages of electron density, ion composition, electron temperature, and ion temperature in the altitude range 50 to 1500 km with extrapolated output up to 2000 km [*Bilitza and Reinisch,* 2008]. The International Reference Ionosphere (IRI) is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI) and is the de facto international standard for climatological specification of ionospheric quantities. Updated frequently, several steadily improved editions of the model have been released over the years based on major data sources

including the worldwide network of ionosondes, the powerful incoherent scatter radars (Jicamarca, Arecibo, Millstone Hill, Malvern, St. Santin), the ISIS and Alouette topside sounders, and in situ instruments on several satellites and rockets (see http://iri.gsfc.nasa.gov/). While IRI is capable of specifying a variety of other quantities, the AF-GEOSpace implementation calculates only electron density, neutral, ion, and electron temperatures and ion densities (O^+, H^+, He^+, O^+_2, NO^+, and N^+).

IRI2007 Inputs

The IRI2007 Science Module requires the following inputs:

Global Parameters: Year, Day, UT

Note: Input values for *F10.7* and *Ap* are read directly from the file $AFGS_HOME/models/data/IRI2007/ap.dat. File updates are made available periodically via FTP. The values entered in the *Globals* input section are not utilized.

Required Data files: IRI2007 retrieves all input quantities (except for the time) from data files found in folder $AFGS_HOME/models/data/IRI2007, namely

dgrf##.dat, igrf05.dat, igrf05s.dat: Definitive IGRF and IGRF coefficients for the years 1945-2010 (## = two-digit year)

CCIR##.asc: Coefficient files for the CCIR model (## = month + 10)

URSI##.asc: Coefficient files for the URSI model (## = month + 10)

ig_rz.dat: File contains (1) the ionospheric index (IG12) based on foF2 measurements from a dozen ionosondes correlated with CCIR foF2 maps [*Liu et al.,* 1983] and (2) the 12-month running mean of sunspot number (Rz12) for 1958 thru 2013. If a date outside this range is used, no valid output will be generated and all output quantities will be set to values of -1. File updates are made available periodically via FTP.

ap.dat: Contains 3-hour *Ap* magnetic index and F10.7 daily index from 1958 thru Feb 2011. If a date outside this range is used, then the *Ap*-dependent "foF2 storm model" [*Fuller-Rowell et al.*, 2000; *Araujo-Pradere et al.,* 2002] will be turned off. File updates available periodically via FTP.

The eight input options offered below were chosen from a larger list of available IRI options on the basis of likelihood of selection as well as their lack of additional input/database requirements.

Bottomside Thickness: The bottomside thickness can be specified two ways:

Internal table: This coefficient table (B_0) is based on incoherent scatter data [see *Bilitza et al.,* 2000].

Gulyaeva model: The *Gulyaeva model* is based on ionosonde data mostly from mid-latitiudes [*Gulyaeva,* 1987].

F Layer:	Global representation of the F2 peak parameters (FoF2, M3000) are available from two models:	
	URSI model:	Model of the International Union of Radio Science (URSI)
	CCIR model:	Model of the Comite´ Consultatif International des Radiocummnications (CCIR) [*CCIR*, 1967]
	The *CCIR model* is recommended for the continents and the *URSI model* for the ocean areas. If a single model is needed globally then the *URSI model* is recommended.	
Ion Composition:	Ion composition representation is available from one of two sets of models.	
	DS-95 and TTS-03:	The models of Danilov-Smirnova [*Danilov and Smirnova,* 1995] and Truhlik, Triskova, Smilauer [*Truhlik et al.,* 2003] will be used.
	DS-78 and DY-85:	The models of *Danilov and Semenov* [1978] and *Danilov and Yaichnikov* [1985] will be used.
Te calculation:	The electron temperature can be specified two ways.	
	Standard:	Use the standard electron temperature description
	Te/Ne correlation:	Use electron temperature based on correlation with density.
Ne calculation:	The electron density can be specified two ways.	
	Standard:	Use the standard electron density description.
	Lay-functions:	Use normalized electron density using lay-functions.
F1 calculation:	The F1 plasma frequency can be specified two ways [*Bilitza,* 2001].	
	Standard:	The frequency foF1 is from the IRI-95 model [*DuCharme et al.,* 1971, 1973]
	L-condition transitions:	This option adds the so-called L-condition transitions developed by *Scotto et al.* [1997, 1998].
Topside Ne calculation:	Two options are available for the topside electron density profile.	
	Intercosmos:	The Intercosmos-based topside model based on *Truhlik et al.* [2006].
	Te tops (Aero, ISIS):	The standard IRI model based on Aeros/ISIS data.
Topside Te calculation:	Topside electron density profile computation can be	
	NeQuick:	The topside model based on *Radicella and Leitinger* [2001] and *Coisson et al.* [2006] is used.
	TTS:	The topside model based on *Truhlik et al.* [2006] is used.

Corrected IRI 2001: Correction factors from *Bilitza* [2004] are used within the original 2001 topside model.

Original IRI 2001: The original 2001 model is used.

Note: The code implementation within the IRI-2007 Science Module follows all default option settings of the original FORTRAN code. For completeness, options not offered above but which are accessible in the original code are listed here along with their default settings. Chart notation comes directly from file *irisub.for* acquired via the FTP code source.

```
  .True.                    .False.                          default
--------------------------------------------------------------------
Ne computed               Ne not computed                      true
Te, Ti computed           Te, Ti not computed                  true
Ne & Ni computed          Ni not computed                      true
Ne - Tops: f10.7<188      f10.7 unlimited                      true
foF2 from model           foF2 or NmF2 - user input            true
hmF2 from model           hmF2 or M3000F2 - user input         true
foF1 from model           foF1 or NmF1 - user input            true
hmF1 from model           hmF1 - user input (only Lay version) true
foE  from model           foE or NmE - user input              true
hmE  from model           hmE - user input                     true
Rz12 from file            Rz12 - user input                    true
IGRF dip, magbr, modip    old FIELDG using POGO68/10 for 1973  true
F1 probability model      critical solar zenith angle (old)    true
ion drift computed        ion drift not computed              false
ion densities in %        ion densities in m-3                 true
D-region: IRI-95          Special: 3 D-region models           true
F107D from AP.DAT         F107D user input (oarr(41))          true
foF2 storm model          no storm updating                    true
IG12 from file            IG12 - user input                    true
spread-F probability      not computed                        false
--------------------------------------------------------------------
```

IRI2007 Outputs

The IRI2007 Science Module returns 3D Gridded data sets of electron density (#/m^3), temperatures (°K) of neutrals, ions, and electrons, and densities of O^+, H^+, He^+, O_2^+, NO^+, and N^+.

The ISPM Science Module (V2.5.1 and Static Only)

Model Name:	Interplanetary Shock Propagation Model (ISPM)
Version:	94
Developer:	M. Dryer and Z. Smith, NOAA Space Environment Center
References:	Fry, C. D., M. Dryer, Z. Smith, W. Sun, C.S. Deehr, and S.-I. Akasofu, Forecasting solar wind structures and shock arrival times using an ensemble of models, *J. Geophys. Res.*, *108*(A2), 1070, doi:10.1029/2002JA009474 (2003)
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Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

ISPM Overview

The Interplanetary Shock Propagation Model (ISPM) was developed to estimate the characteristics of interplanetary shocks caused by energetic solar events. We hereafter refer to these shock-producing solar events, whether they are coronal mass ejections or solar flares, as "solar flares" since flare data are a crucial input to the model. This description of ISPM is excerpted from the User's Manual:

> "The ISPM program calculates the arrival time and strength at 1 AU of a shock from a solar flare. The shock strength is characterized by the jump in dynamic pressure across the shock front: this parameter is used to estimate the likelihood of the shock being geo-effective. The arrival time and strength are calculated from algebraic equations derived from a parametric study of solar-caused interplanetary shocks that was made using [two-dimensional magnetohydrodynamic] simulations."

ISPM is based on magnetohydrodynamic computations of a shock wave initiated at the Sun that propagates through a normal solar wind. The initial energy of the shock is estimated by a formulation based on the X-ray energy output of a solar flare and the associated speed derived from the Type II frequency drift rate. The angular extent of the shock wave from the presumed solar flare location is a function of the energy estimated by this formulation.

As input, the ISPM requires specification of the flare location, start time of the shock, shock driver duration, and initial shock speed. The flare location (solar latitude and longitude) is obtained from H-alpha observations made by USAF SOON sites. The shock start time is defined

as the onset time of the Type II radio burst associated with the flare as observed by the USAF RSTN sites. Initial shock speed is set to the Type II drift speeds estimated by the RSTN sites. Shock duration times can either be directly input or estimated from the decay time of the soft X-ray event associated with the solar flare. If the X-ray level option is chosen, the ISPM assumes the shock driver end time to be the time at which the logarithm of the magnitude of the GOES satellite 1-8 Angstrom X-ray signal falls to one-half the logarithm of the peak value observed for the event.

For output, the ISPM gives the predicted transit time (TT) of the shock from Sun to Earth and its strength in terms of the dynamic pressure jump (DPJ) across the shock front and the shock strength index (SSI). According the ISPM User's Manual, the SSI "is based on the difference of (the log10 of) the DPJ from the [background] state used in the numerical modeling study." If the SSI is greater than or equal to zero then the shock will likely be geo-effective. If SSI is less than -1 there will likely be no measurable effects. TT and DPJ are provided by numerical algorithms relating TT and DPJ to total net energy (E) input by the solar source into the interplanetary medium as a function of angular separation ϕ between observer and solar source. The algorithms were constructed in algebraic form from a parametric study that used representative combinations of the shock starting velocity and starting pulse width and duration.

The range of applicability is given by *Smith and Dryer* [1994] as follows,

Solar flare input energy, E	$E > 10^{29\ \mathrm{erg}}$
Angular distance of pulse central meridian from Earth-sun line, ϕ	-90 deg < ϕ < 80 deg
Transit time, TT	TT < 120 hours

The flare input energy can be estimated from the pulse duration time T_d and the initial shock speed Vs according to the formula, $E = C{*}\omega{*}(Td + D){*}(Vs^3)$ with C=2.83e+19 erg/(m^3 s^2 deg), the pulse longitudinal width ω=60 degrees, and D=0.52 hours. Total energy is assumed to be proportional to kinetic energy flux, i.e., V_s^3. The spatial input pulse shape is a sine curve of width ω, where the area under the sine curve is proportional to ω. The temporal input pulse has a flat section of width T_d with 1-hour ramps at the beginning and end of the pulse.

ISPM Inputs

The ISPM science module requires the following inputs:

Global Parameters: Year, Day, UT (used to initialize event onset and end times)

Specify Event Duration: The user can choose to specify either the *Stop Time* of the event, the *Duration* of the event, or have the event duration estimated from inputs of the associated GOES soft *X-ray Levels*.

Event onset time: Time of onset of Type II radio burst from USAF RSTN site in the format MM/DD/YY HH:MM.

Event end time: When *Stop Time* is selected to specify the event duration, the user inputs here the event end time in the format MM/DD/YY HH:MM. GOES satellite X-ray levels are not used to estimate the event duration. The ISPM resets any duration greater than 2 hours to 2 hours.

Event duration: When *Duration* is selected to specify the event duration the user inputs the event duration in hours here. GOES satellite X-ray levels are not used to estimate the event duration. The ISPM resets any duration greater than 2 hours to 2 hours.

Backg. Class: When *X-ray Levels* is selected to specify the event duration, the user inputs here the background X-ray level measured by the 1-8 Angstrom X-ray instrument on a GOES satellite before the event occurred. These values are entered with a classification letter and a numeric field. The usual X-ray event classification letters A, B, C, M, or X can be used with the numeric field consisting of 1-3 characters which may be digits or an optional decimal point. The numeric field multiplies the flux level. The range of allowed values is A1 through X99.

Peak. Class: When *X-ray Levels* is selected to specify the event duration, the user inputs here the peak X-ray level measured by the 1-8 Angstrom X-ray instrument on a GOES satellite during the X-ray event. The format is the standard X-ray event classification scheme as explained above. After entering this value the user should click in the *Decay time* box and the level corresponding to 1/2 log of the peak signal will be displayed next to this box.

Decay time, level XN.N: When *X-ray Levels* is selected to specify the event duration the user inputs here the time in the format MM/DD/YY HH:MM at which the X-ray level measured by the 1-8 Angstrom X-ray instrument on a GOES satellite during the X-ray event decays to the level XN.N. The *level XN.N* is calculated from the *Backg. Class.* and *Peak. Class*. Of course, this time will occur after the peak of the X-ray event.

Type II speed (km/s): The Type II drift speed in km/s calculated by the USAF RSTN network from observations of Type II radio bursts. This value must be greater than 0 and less than 10000 km/s.

Flare lat. (deg N): The solar latitude, between -90^o and +90^o North, of the solar flare associated with the Type II radio burst. This information can be obtained from H-alpha observations by the USAF SOON sites. Degrees South are entered as negative numbers. ISPM does not use this input.

Flare lon. (deg W).: The solar longitude, between -180^o and +180^o West, of the solar flare associated with the Type II radio burst. This information can be obtained from H-alpha observations by the USAF SOON sites. Degrees East are entered as negative numbers. Note: Flare locations beyond the limb are unrealistic.

Event in previous 24 hours?: If the user checks this box then the following guidelines concerning the interpretation of the ISPM are displayed in a text window:

> If an event has occurred in the previous 24 hours, you need to check for the possibility of interaction of the shock from this event with that from the previous event.

If the first shock arrives well before the expected arrival of the second shock, the first shock is independent. If not, you need to look at the relative spacing of sources in space and time.

If the source of the first shock (F1) is within 25 deg of Central Meridian (CM) [the Earth-Sun line] its reverse shock (R1) will interact with the forward shock of the following event (F2). If R1 is strong enough, F2 may be significantly weakened or even annihilated in the interaction. In this case, F1 may travel independently to 1AU. (Note: reverse shocks form some 5-10 hours after initiation of a flare. If the time interval between the two flares is too short, the reverse shock may not have had time to form).

If not, F1 is likely to be overtaken. In this case, the ISPM prediction does not apply to either F1 or F2.

The shock from the second event (F2) will be independent if:

1. F2 is significantly faster than F1, its source is located closer to CM than F1 and it starts soon after F1 (within a few hours).

2. F2 travels independently for the majority of its transit time to Earth. That is:

   a. It does not encounter R1 (source of F1 is >30 deg from CM).

   b. It does not travel through the high-speed wake of F1.

In case 2.a, an encounter with a reverse shock will weaken or annihilate a fast forward shock. The exact nature of the resultant of the interaction depends on the relative strength of the interacting shocks. In case 2.b, traveling through the disturbed (high speed, low density) wake of a preceding fast forward shock will accelerate the following shock.

If a prediction for the previous event is not available you can get it by running ISPM for it separately.

Display Text: Clicking this button will display the text output window if currently closed.

ISPM Outputs

ISPM returns a text message window containing the results of the model calculations and a summary of the input parameters. The model outputs are:

Time of shock arrival at Earth in the format YYYY MM DD HHMM (Zulu)

Total propagation time in the format HH MM

Shock Strength (the dynamic pressure jump, DPJ) in units of dynes/cm^2

In addition, ISPM computes the shock strength index (SSI) based on the difference of (the log10 of) the DPJ from the [background] state used in the numerical modeling study. If the SSI is greater than or equal to zero then the shock will likely be geo-effective. If SSI is less than -1 there will likely be no measurable effects.

The MAGNETOPAUSE Science Module

Model Name: Magnetopause

Version: 9 Aug 2009

Developer: Air Force Research Laboratory (based on the magnetopause location code of N. A. Tsyganenko; GEOPACK-2008 software version 21 April 2008)

References:

Jerab, M., Z. Nemecek, J. Safrankova, K. Jelinek, and J. Merka, Improved bow shock model with dependence on the IMF strength, *Planet. Space Sci., 53*, 85-93 (2005)

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Shue, J.-H., C.T. Russell, and P. Song, Shape of the low-latitude magnetopause: Comparison of models, *Adv. Space Res., 25*, 1471-1484 (2000)

Shue, J.-H., and P. Song, The location and shape of the magnetopause, *Planet. Space Sci., 50*, 549-558 (2002)

Tsyganenko, N.A., S.B.P. Karlsson, S. Kokubun, T. Yamamoto, A.J. Lazarus, K.W. Ogilvie, C.T. Russell, and J.A. Slavin, Global configuration of the magnetotail current sheet as derived from Geotail, Wind, IMP 8 and ISEE ½ data, *J. Geophys. Res., 103 (A4)*, 6827-6841, (1998)

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Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

Magnetopause Overview

Solar wind interaction with the Earth's internal magnetic field forms a magnetic cavity called the magnetosphere. The outer boundary of this cavity is called the magnetopause which is shaped by interactions of the internal fields and particle populations of the magnetosphere with the streaming solar wind particles and the Interplanetary Magnetic Field (IMF) flowing past the

Earth. The magnetopause boundary is the location where mass, energy, and momentum from the solar wind are exchanged with the magnetosphere. As a result, the characteristics of the magnetic field and charged particle populations can be extremely different on either side of this boundary, e.g., the magnetic field component perpendicular to the geosynchronous orbit plane can change sign abruptly as a spacecraft crosses the magnetopause. Characteristics of the charged particle populations can also vary rapidly across this boundary. To assist with determining spacecraft location relative to this important physical boundary, the MAGNETOPAUSE Science Module specifies the location of the Earth's magnetopause boundary using the model of *Shue et al.* [1998] which is driven by solar wind dynamic pressure and the z-component of the IMF. The basic output of the model is the distance measured in Earth radii to the magnetopause boundary so it can be used to estimate the timing of spacecraft magnetopause crossings.

Magnetopause Inputs

The Magnetopause science module requires the following inputs:

Global Parameters: Year, Day, UT

The *Solar Wind* section allows the user to specify how the solar wind input will be characterized. Input text boxes will activate according to the chosen method. Note that the default settings represent typical solar wind conditions and that all methods require the same Interplanetary Magnetic Field (IMF) information. The three options are:

Velocity + Density: The *Velocity + Density* option requires input of the following quantities:

VGSE-X (km/s), VGSE-Y (km/s), and *VGSE-Z (km/s)* are the GSE X, Y, and Z velocity components of the solar wind. In the Geocentric Solar Ecliptic (GSE) coordinate system, the X axis points from the Earth to the Sun (thus *VGSE-X (km/s)* < 0), the Z axis is perpendicular to the ecliptic plane (positive towards north), and the Y axis completes the right-handed system.

SW-Density ($\#/cm^3$) is the solar wind proton number density.

IMF-Bz(nT) is the GSE z-component of the IMF.

Speed + Density: The *Speed + Density* option requires input of the following quantities:

SW-Speed (km/s) is the solar wind speed.

SW-Density ($\#/cm^3$) is the solar wind proton number density.

IMF-Bz(nT) is the GSE z-component of the IMF.

Note that this option assumes *VGSE-X(km/s)* = -[*SW-Speed (km/s)*] and *VGSE-Y (km/s)* = *VGSE-Z (km/s)* = 0 to determine the aberration angle.

Dynamic Pressure: The *Dynamic Pressure* option requires input of the following quantities:

SW-Press (nPa) is the solar wind dynamic pressure in units of nanoPascal.

IMF-Bz(nT) is the GSE z-component of the IMF.

Note that this option automatically sets *VGSE-X(km/s)* = -400 km/s and *VGSE-Y (km/s)* = *VGSE-Z (km/s)* = 0 to determine the aberration angle.

GSW Aberration Correction: Checked by default, selecting the *Add 29.78 km/s to VGSE-Y* box assumes, as is typically the case in available data sets, that the value used for *VGSE-Y (km/s)* was already reduced by that amount in order to account for the aberrations caused by Earth's orbital motion around the Sun. Note that the "Geocentric Solar-Wind" (GSW) coordinate system is analogous to the GSM system except it's X-axis is align anti-parallel to the actual observed direction of solar wind flow. With this correction selected and given average solar wind conditions, the magnetopause boundary surface will rotate ~4° about the GSE Z-axis such that the magnetotail swings toward the GSE-Y direction.

Magnetopause Outputs

The MAGNETOPAUSE Science Module returns a 3D Gridded Data Set of the *Distance* measured in Earth radii to the magnetopause boundary with positive and negative values corresponding to points inside and outside the magnetopause, respectively. A summary of selected model inputs and assumed values will appear listed in the *Model Status* box.

The METEOR IMPACT MAP Science Module

Model Name: Meteor Impact Map Model

Version: February 2004

Developer: Radex, Inc. (now AER, Inc.) and the Air Force Research Laboratory

References:

Ceplecha, Z., J. Borovicka, W.G. Elford, D.O. Revelle, R.L. Hawkes, V. Porubcan, and M. Simek, Meteor Phenomena and Bodies, *Space Sci. Rev.*, *84*, 327-471 (1998)

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Jenniskens, P., Meteor stream activity: I. The Annual Streams, *Astronomy and Astrophysics., 287*, 990-1013 (1994)

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Love, S. G., and D. E. Brownlee, A Direct Measurement of the Terrestrial Mass Accretion Rate of Cosmic Dust, *Science*, *262*, 550-553 (1993)

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McDonnell, J.A.M., and K. Sullivan, Hypervelocity Impacts on Space Detectors: Decoding the Projectile Parameters, *Proceedings of the Workshop on Hypervelocity Impacts in Space*, U. of Kent, Canterbury, UK, 1-5 July (1991)

McKinley, D. W. R., *Meteor Science and Engineering*, McGraw-Hill, New York (1961)

McNeil, W. J., E. Murad, and J. M. C. Plane, Models of Meteoric Metals in the Atmosphere, in *Meteors in the Earth's Atmosphere*, edited by E. Murad and I.P. Williams, Cambridge University Press, Cambridge, UK, 265-287 (2002)

Williams, I.P., and E. Murad, Introduction, in *Meteors in the Earth's Atmosphere*, edited by E. Murad and I.P. Williams, Cambridge University Press, Cambridge, UK, 1-11 (2002)

Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

METEOR IMPACT MAP Overview

Meteors enter the Earth's atmosphere during well-known meteor shower periods, as well as at irregular periods. The former are attributed to dust released by comets as they approach perihelion (an exception to this statement being that the Geminids arise from the fragmentation of Asteroid Phaethon), while the latter represent a variety of sources, such as cosmic dust,

meteoroids that have scattered by collisions, and fragmentation of asteroids and meteorites following collisions (see *Ceplecha et al.,* [1998] and *Williams & Murad* [2002] for detailed introductions). In total about 40,000 tons of extraterrestrial matter are captured by Earth annually, most of which disappears during reentry due to the high temperatures achieved due to frictional heating [*Love & Brownlee*, 1993]. The vaporization process occurs primarily in the E-region of the ionosphere, at altitudes between 130 and 90 km (Cf. review by *McNeil et al.*, [2002]). The meteor showers are generally quite well known and most of the meteoroids consist of particles that have masses in the range 1 μg – 10 mg with a peak near 10 μg [*Love & Brownlee*, 1993].

The extraterrestrial matter enters the Earth at high velocities that vary between 12 km/s and 70 km/s, the exact velocity depending on the relative positions of Earth in its orbit and of the dust cloud. Because of this high velocity, even the smallest of the meteoroids can cause severe damage to spacecraft upon impact. The damage can be in the form of surface damage (weakening of the surface through formation of pits, or perhaps penetration) or generation of plasma with consequent damage to electrical systems on board of spacecraft. This module provides several pieces of information that are useful in the evaluation of meteoric phenomena as sources of anomalies on spacecraft.

Two important characteristics of meteors are the radiant (the point where the backward projection of the meteor trajectory intersects the celestial sphere or more generally, the point in the sky where meteors from a specific shower seem to come from) and the Zenithal Hourly Rate (ZHR - the number of shower meteors per hour one observer would see if his limiting magnitude is 6.5, and if the radiant is in the zenith). Generally, the known showers are relatively weak, corresponding to a zenithal hourly rate (ZHR) of 200 or less. However, occasionally a storm occurs during an orbital conjunction of the Earth and cometary dust. In those cases, the ZHR may be as high as 10,000 for a short time (1-2 hours). Another important characteristic is the visual magnitude, M, of a meteor. This magnitude is an arbitrary visual scale related to the absolute luminous power (I) by the formula: $M = 6.8 - 2.5 \log[I]$, where I is given in watts radiated by the meteor (Öpik, quoted by *McKinley* [1961]). We will not make use of this quantity in this part of the meteor module.

The Meteor Impact Map Model calculates the rate of meteor impacts on a user-specified surface area at positions outside of the Earth's atmosphere. For the specified date, the shower database is used to determine the active showers, their intensity, direction of travel, and mass distribution characteristics. The "damage" calculations are based on the work of *McDonnell and Sullivan* [1991], who derived material penetration formulas based on the size, density and velocity of the incident meteor and the material properties. Given the user-selected satellite material properties and the characteristics of each active shower, the minimum meteor mass (for each shower) required to cause the specified damage is calculated. The *Love and Brownlee* [1993] mass distribution characteristics are used to determine the number of meteors per second at or above this mass that will be present. This flux rate is then multiplied by a user-specified surface area to determine the impact rate. The effects on the damage of varying angles of meteor impacts on the surface is ignored due to the satellite-specific geometry that would be required for proper modeling. By assuming all meteor impacts are exactly perpendicular to the surface, this gives the "worst-case" scenario. For the "damage" calculations, the Earth's shadowing of meteors is included in the model. Meteor showers that are blocked by the Earth from reaching the model's specific grid positions, or the positions along a satellite path, are removed from the impact rate

calculation at those points. The "flux only" calculations are an extension of the damage-type calculations. Because no material or pit depth is specified, the selection of a minimum meteor mass is handled in a different manner. A method has been derived to normalize the effects of the varying velocities between the different showers. This method relates a minimum pressure-like value imposed by impacting meteors to calculate the minimum mass for each shower. The "flux-only" calculations do not take into account any Earth-shadowing of the meteor showers.

The essential part of the meteor model code is a database that describes the annual meteor showers. *Jenniskens* [1994] produced a set of parameterized values for describing 50 annual meteor showers (note that these differ from those posted by the International Meteor Organization at www.imo.net). Given a date and time, the shower parameters are used in Jenniskens' equations to calculate the current intensity and radiant position (which defines the direction of travel) for each of the currently active showers. This database also includes each shower's typical meteor velocity and particle size distribution parameter. *McBride* [1997] made some revisions and updates to this database of shower parameters. A fixed set of parameters has been assigned for the "sporadics" shower, though without a radiant position. The meteor mass distribution derived by *Love and Brownlee* [1993] is used for calculating the number of meteors per second (flux) at or above/below a certain mass, depending on the application. When a user includes an optional storm, its basic characteristics are based on the associated shower. However, the intensity of the storm is modeled as a Gaussian curve, reaching the specified maximum ZHR value at the storm peak time, and dropping off towards zero symmetrically before and after the peak.

If the user is interested in examining the influence of meteoroid showers on spacecraft orbits over an extended period, then the METEOR IMPACT-APP module should be used.

METEOR IMPACT MAP Reference Data

Reference materials describing annual meteor shower activity can be accessed using the set of three buttons at the top of the Meteor Impact Environment Window.

Flux Sums	The *Flux Sums* button displays a single page PDF with a plot of "Annual Meteor Shower Flux (#/meter^2/s)" for a typical year. Most flux peaks are labeled with the name of the dominant shower.
ZHR Sums	The *ZHR Sums* button displays a single page PDF with a plot of "Zenithal Hourly Rate (ZHR) Sum of Active Showers" and a plot of "Number of Active Showers" for a typical year. Most ZHR sum peaks are labeled with the name of the dominant shower.
Annual Shower Table	The *Annual Shower Table* button displays a text dialog (matching Table 1) with a list of meteor showers with basic features, i.e., Shower Name, Julian Day of Year (DOY) Range, Peak Date, Zenithal Hourly Rate at the peak date (i.e., ZHR@Peak), Calendar Date Range, and velocity (km/s).

TABLE 1

Shower Name	(DOY Range)	PeakDate	ZHR@Peak	Date Range	V(km/s)
Bootids	(002-006)	04 Jan	127.22	02Jan-06Jan	43.0
gamma-Velids	(359-018)	06 Jan	2.39	25Dec-18Jan	35.0
alpha-Crucids	(003-029)	16 Jan	2.99	03Jan-29Jan	50.0
alpha-Hydrusids	(009-032)	20 Jan	2.00	09Jan-01Feb	44.0
alpha-Carinids	(023-040)	31 Jan	2.29	23Jan-09Feb	25.0
delta-Velids	(028-048)	07 Feb	1.29	28Jan-17Feb	35.0
alpha-Centaurids	(029-050)	08 Feb	7.26	29Jan-19Feb	57.0
omicron-Centaurids	(035-052)	12 Feb	2.18	04Feb-21Feb	51.0
theta-Centaurids	(039-068)	23 Feb	4.48	08Feb-09Mar	60.0
delta-Leonids	(034-075)	24 Feb	1.10	03Feb-16Mar	23.0
Virginids	(049-070)	29 Feb	1.50	18Feb-11Mar	26.0
gamma-Normids	(063-079)	13 Mar	5.76	04Mar-20Mar	56.0
delta-Pavonids	(079-114)	31 Mar	5.28	20Mar-24Apr	60.0
Lyrids	(102-122)	22 Apr	12.67	12Apr-02May	49.0
mu-Virginids	(120-151)	30 Apr	2.20	30Mar-31May	30.0
eta-Aquarids	(093-160)	06 May	36.66	03Apr-09Jun	66.0
alpha-Scorpiids	(124-148)	16 May	3.18	04May-28May	35.0
beta-Australids	(122-150)	16 May	3.00	02May-30May	45.0
omega-Scorpiids	(141-165)	02 Jun	5.18	21May-14Jun	21.0
day-Arietids	(130-187)	07 Jun	53.97	10May-06Jul	38.0
gamma-Sagitarids	(132-210)	20 Jun	2.40	12May-29Jul	29.0
tau-Cetids	(088-267)	27 Jun	3.60	29Mar-24Sep	66.0
tau-Aquarids	(172-188)	29 Jun	7.10	21Jun-07Jul	27.0
theta-Ophiuchids	(142-219)	29 Jun	2.30	22May-07Aug	63.0
v-Phoenicids	(187-201)	13 Jul	4.97	06Jul-20Jul	48.0
o-Cygnids	(188-211)	19 Jul	2.49	07Jul-30Jul	37.0
Capricornids	(171-240)	25 Jul	2.20	20Jun-28Aug	25.0
delta-Aquarids(N)	(191-224)	26 Jul	1.00	10Jul-12Aug	42.0
Pices-Australids	(202-214)	27 Jul	2.89	21Jul-02Aug	42.0
delta-Aquarids(S)	(185-232)	28 Jul	11.37	04Jul-20Aug	43.0
iota-Aquarids(S)	(198-233)	03 Aug	1.50	17Jul-21Aug	36.0
Perseids	(209-239)	12 Aug	83.78	28Jul-27Aug	61.0
kappa-Cygnids	(210-251)	19 Aug	2.29	29Jul-08Sep	27.0
epsilon-Eridanids	(219-255)	25 Aug	39.81	07Aug-12Sep	59.0
gamma-Doradids	(231-250)	28 Aug	4.76	19Aug-07Sep	41.0
Aurigids	(232-253)	31 Aug	8.93	20Aug-10Sep	69.0
kappa-Aquarids	(249-276)	19 Sep	2.69	06Sep-03Oct	19.0
epsilon-Geminids	(274-310)	19 Oct	2.90	01Oct-06Nov	71.0
Orinids	(274-314)	21 Oct	24.98	01Oct-10Nov	67.0
Leo-Minorids	(286-305)	22 Oct	1.89	13Oct-01Nov	61.0
Taurids	(236-016)	05 Nov	7.29	24Aug-16Jan	30.0
delta-Eridanids	(305-324)	11 Nov	0.90	01Nov-20Nov	31.0
squiggle-Puppids	(306-329)	14 Nov	3.19	02Nov-25Nov	41.0
Leonids	(315-327)	17 Nov	22.77	11Nov-23Nov	71.0
Puppids	(289-021)	03 Dec	4.50	16Oct-21Jan	40.0
Phoenicids	(333-343)	04 Dec	2.79	29Nov-09Dec	18.0
Monocerotids	(341-351)	12 Dec	2.00	07Dec-17Dec	43.0
Geminids	(340-355)	13 Dec	87.85	06Dec-21Dec	36.0
sigma-Hydrusids	(337-364)	17 Dec	2.49	03Dec-30Dec	59.0
Ursids	(353-359)	22 Dec	11.68	19Dec-25Dec	35.0

METEOR IMPACT MAP Inputs

The METEOR IMPACT science module requires the following inputs,

Global Parameters: Year, Day, and UT (Kp, SSN, F10.7 and Ap are not used).

Meteor shower fluxes can be determined using two different *Count Methods*,

Flux Only: Select the *Flux Only* option to specify the total meteor shower hourly impact rate on an assumed cross sectional area of 1 square meter. Sporadic meteors are included if the *Sporadics* option is also selected (see below).

Damage: Selecting the *Damage* option to account for only those meteors that will intersect a user-defined cross sectional area and damage a given material type by exceeding a prescribed pit depth threshold. Sporadic meteors are included if the *Sporadics* option is also selected (see below). Selecting the *Damage* option requires the following additional inputs,

Cross Section: The cross section of the material of interest (m^2)

Pit Depth: The threshold minimum pit depth (mm) causing by a meteor impact.

Material Type: Fixed material options include aluminum, copper, stainless steel, beryllium/copper, iron, silver, platinum, gold, titanium, Mylar, and glass.

User Def: Select this option to set the user-defined material characteristics *Density* (g/cm^3) and *Tensile* strength (MPa).

Sporadics: The *Sporadics* option adds sporadic meteors and dust to the *Flux Only* or *Damage* calculations above. Sporadic meteors are considered to be random occurrences and not associated with a particular meteor shower. Note that the sporadic meteors occur year-round. The exclusion of the Sporadic meteors can be useful when studying low activity periods of the annual showers, where their effects could be masked by the sporadics.

The *Storm Simulation (Optional)* section allows user-defined meteor storms to be <u>added</u> to the annual meteor showers that are active at the specified date. Meteor storm characteristics are defined in terms of (1) an active associated shower, (2) the peak Zenithal Hourly Rate, (3) a storm peak time, and (4) the storm duration. Once the parameters are set for the user-defined storm, use the *Add* button to place the storm in the active list located just above the *Add* and *Delete* buttons. Use the *Delete* button to remove storms from the active list. A maximum of five storms may be specified. The meteor storm input parameters include the following:

Shower Name: To create a meteor storm associated with a particular shower, use the selector button to browse the list of named showers. For a meteor storm to be properly applied, the run-time Day entered at the globals section must fall within the valid day-of-year range noted in parentheses next to the shower name.

ZHR Max: To set the size of the meteor storm, enter the Zenithal Hourly Rate maximum in the *ZHR Max* text box. Note that as a guide, the *Shower Data* button contains the typical ZHR@Peak value and velocity for each shower.

Two methods are provided for specifying meteor storm time and duration,

Solar Long/Duration Delta: If the *Solar Long/Duration Delta* method is selected, center the meteor storm on a specific time by entering the Solar Longitude value in degrees into the *Solar Long* text box. Set the length of the storm in degrees using the *Duration Delta (deg)* text box. Note that 1-hour is equal to ~0.042 degrees solar longitude. The maximum allowed storm duration is 0.5 degrees (~12 hours). Tables of solar longitude versus day-of-year equivalents can be found at the International Meteor Organization website (www.imo.net). Zero degrees solar longitude generally occurs on or about 20 March.

Date/Duration: If the *Date/Duration* method is selected, center the meteor storm on a specific time by using the *Year*, *Day*, *Hour*, *Minute* text boxes and set the length of the storm in hours using the *Duration (Hr)* text box. The maximum allowed storm duration is 12 hours.

METEOR IMPACT MAP Outputs

The METEOR IMPACT MAP science module returns a 3D Gridded Data Set representing the hourly impact rate (meteors/hour) for the single time entered in the Globals section. Using the *Flux Only* mode, the hourly impact (on a cross sectional area of 1 m^2) includes meteors from all showers active at the run time. Using the *Damage* mode, the hourly impact output includes only those meteors that would impact the user-defined material area and result in damage to at least the user-defined pit depth. We recommend displaying output in 2D or 3D plots using the COORD-SLICE graphical object. The geometry of multiple coincident shows can be viewed using the ISOCONTOUR graphical object.

The SATEL-APP application and ORBIT PROBE graphics modules can be used together to view hourly meteor impact rates along an orbit path, but the result is only approximate if the science module is run in static mode. While a dynamic science module run can be performed and a satellite flown though stepped outputs, a much more realistic estimate of the hourly impact of meteors along a satellite orbit can be obtained by using the application designed specifically for this purpose, namely METEOR IMPACT-APP.

The METEOR SKY MAP Science Module

Model Name:	Meteor Ground-Based Sky Map Model
Version:	February 2004
Developer:	Radex, Inc. (now AER, Inc.) and the Air Force Research Laboratory

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Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

METEOR SKY MAP Overview

The METEOR SKY MAP science module calculates the number of visible meteors from the active meteor showers (and any user-specified storms) at the specified date, over a grid of ground-level positions covering the entire globe. An unobstructed field of view of the sky is assumed, with conditions permitting meteors of 6.5 magnitude or brighter to be observed.

Meteor shower intensities are expressed in a zenith hourly rate, or ZHR [see Table 1 of the previous section (The METEOR IMPACT MAP Science Module) or access the *Annual Shower Table* button in the Environment Window]. These values are estimates of the number of visible meteors per hour when the shower's radiant is at the zenith (directly overhead) of the observer's location, and under optimal viewing conditions. The number of viewable meteors decreases considerably due to atmospheric effects and geometry (i.e., the horizon) as the shower's radiant and observer position become separated by a larger angular extent. The apparent brightness of the meteors decreases as a function of this angular distance, causing many to fall below the 6.5 magnitude brightness viewing threshold. The sporadic meteors, however, are treated differently. While no true shower radiant exists, the intensity of the sporadic meteors is modeled to vary with both local time and geographic latitude.

METEOR SKY MAP Reference Data

Reference materials describing annual meteor shower activity can be accessed using the set of three Database buttons at the top of the METEOR SKY MAP Environment Window.

Flux Sums — The *Flux Sums* button displays a single page PDF with a plot of "Annual Meteor Shower Flux (#/meters^2/s)" for a typical year. Most flux peaks are labeled with the name of the dominant shower.

ZHR Sums — The *ZHR Sums* button displays a single page PDF with a plot of "Zenithal Hourly Rate (ZHR) Sum of Active Showers" and a plot of "Number of Active Showers" for a typical year. Most ZHR sum peaks are labeled with the name of the dominant shower.

Annual Shower Table — The *Annual Shower Table* button displays a text dialog with a list of meteor showers with basic features, i.e., Shower Name, Julian Day of Year (DOY) Range, Peak Date, Zenithal Hourly Rate at the peak date (i.e., ZHR@Peak), Calendar Date Range, and velocity (km/s).

METEOR SKY MAP Inputs

The METEOR SKY MAP science module requires the following inputs,

Global Parameters: Year, Day, and UT (Kp, SSN, F10.7 and Ap are not used).

Meteor ground-based sky maps can be produced using two different *Count Methods*,

Flux: The *Flux* count method is used to determine meteoric total flux (#/s/m^2) over the entire Earth's surface. If selected, a value for the limiting low-end *Mass* (grams) must be entered in the text box. Note that the output becomes vanishingly small when the mass reaches approximately 10 grams. Sporadic meteors (see description below) can be included by checking the box to the far right.

Visual: The *Visual* count method is used to determine the meteoric observed Zethinal Hourly Rate (ZHR) from ground level. If selected, a value for the limiting low-end *Magnitude* must be entered in the text box. Note that observed brightness of a meteor decreases as its visual magnitude

increases. Sporadic meteors (see description below) can be included by checking the box to the far right.

Sporadics: The *Sporadics* option adds sporadic meteors and dust to the *Flux* or *Visual* calculations above. Sporadic meteors are considered to be random occurrences and not associated with a particular meteor shower. Note that the sporadic meteors occur year-round. The exclusion of the sporadic meteors can be useful when studying low activity periods of the annual showers, where their effects could be masked by the sporadics.

The *Storm Simulation (Optional)* section allows user-defined meteor storms to be added to the annual meteor showers that are active at the specified date. Meteor storm characteristics are defined in terms of (1) an active associated shower, (2) the peak Zenithal Hourly Rate, (3) a storm peak time, and (4) the storm duration. Once the parameters are set for the user-defined storm, use the *Add* button to place the storm in the active list located just above the *Add* and *Delete* buttons. Use the *Delete* button to remove storms from the active list. A maximum of five storms may be specified. The meteor storm input parameters include the following:

Shower Name: To create a meteor storm associated with a particular shower, use the selector button to browse the list of named showers. For a meteor storm to be properly applied, the run-time Day entered at the Globals section must fall within the valid day-of-year range noted in parentheses next to the shower name.

ZHR Max: To set the size of the meteor storm, enter the Zenithal Hourly Rate maximum in the *ZHR Max* text box. Note that as a guide, the *Shower Data* button contains the typical ZHR@Peak value and velocity for each shower.

Two methods are provided for specifying meteor storm time and duration,

Solar Long/Duration Delta: If the *Solar Long/Duration Delta* method is selected, center the meteor storm on a specific time by entering the Solar Longitude value in degrees into the *Solar Long* text box. Set the length of the storm in degrees using the *Duration Delta (deg)* text box. Note that 1-hour is equal to ~0.042 degrees solar longitude. The maximum allowed storm duration is 0.5 degrees (~12 hours). Tables of solar longitude versus day-of-year equivalents can be found at the International Meteor Organization website (*www.imo.net*). Zero degrees solar longitude generally occurs on or about 20 March.

Date/Duration: If the *Date/Duration* method is selected, center the meteor storm on a specific time by using the *Year*, *Day*, *Hour*, *Minute* text boxes and set the length of the storm in hours using the *Duration (Hr)* text box. The maximum allowed storm duration is 12 hours.

METEOR SKY MAP Outputs

The METEOR SKY MAP science module returns a 2D Gridded Data Set at the Earth surface. If the *Flux* count method was used then the data are given in units of flux (meteors/s/m^2). If the *Visual* count method was used then the data are given in terms of a Zenithal Hourly Rate (ZHR). Display output in 2D or 3D plots using the COORD-SLICE graphics object.

The MSM Science Module (V2.5.1 Only)

Model Name:	Magnetospheric Specification Model (MSM)
Version:	5.20 (November 1996)
Developer:	Rice University and the Air Force Research Laboratory
References:	Gussenhoven, M.S., Hardy, D.A., and Heinemann, N., Systematics of the Equatorward Diffuse Auroral Boundary, *J. Geophys. Res., 88*, 5692-5708 (1983)
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	Hilmer, R.V., and Ginet, G.P., A Magnetospheric Specification Model Validation Study: Geosynchronous Electrons*, J. Atmos. Solar-Terr. Phys., 62*, 1275-1294 (2000) [see $AFGS_HOME\models\REFS\HilmerGinet2000.pdf]
	Rich, F.J., and Maynard, N.C., Consequences of Using Simple Analytic Functions for the High-Latitude Convection Electric Field. *J. Geophys. Res., 94*, 3687-3701 (1989)
	Tascione, T., Kroehl, H.W., Creiger, R., Freeman, J.W., Wolf, R.A. Spiro, R.W., Hilmer, R.V., Shade, J., and Hausman, B., New Ionospheric and Magnetospheric Specification Models. *Radio Sci., 23*, 211-222 (1988)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

MSM Overview

The Magnetospheric Specification Model (MSM) was developed by Rice University for the USAF[3] to address spacecraft charging issues in the inner and middle magnetosphere [*Tascione et al.*, 1988]. It combines theoretical and empirical approaches to make maximal use of real-time

[3] Freeman, Jr., J.W., Wolf, R.A., Spiro, R.W., Voigt, G.-H., Hausman, B.A., Bales, B.A., Hilmer, R.V., Nagai, A., and Lambour, R., Magnetospheric Specification Model Development Code and Documentation. Report for USAF contract F19628-90-K-0012, Rice University, Houston, TX (1993)

data streams so it can respond to changing geophysical conditions on 15-30 minute time scales. The MSM first became operational in 1995. The following is from *Hilmer and Ginet* [2000].

> "The MSM specifies fluxes (#/cm^2/s/sr/keV) of charged particles having energies up to 100 keV (electron, H+, and O+). The model is driven by any combination of parameters with the minimum input requirement being *Kp*. […] The MSM tracks particles in a two-dimensional simulation region as they **E** × **B** and gradient-curvature drift through dawn-dusk symmetric magnetic field configurations with the (Earth centered, spin-aligned) dipole tilt angle fixed equal to zero, i.e., aligned with the GSM z-axis. The inner limit of the modeling region is set at a geocentric distance of 3 Re (Earth Radii). The outer boundary extends from just inside the dayside magnetopause to roughly twice that geocentric distance on the nightside. It remains inside the magnetopause at dawn and dusk local times. A set of regularly spaced ionospheric grid points is magnetically mapped to the simulation plane to define the grid where the particle dynamics are actually tracked. At geosynchronous altitude (~6.6 Re) the resulting grid spacing is typically ~0.2 to 1.0 Re in the radial direction and 7.5° in longitude, i.e., equivalent to 30 minutes for [a geosynchronous] spacecraft.
>
> The magnetic field model (*Hilmer and Voigt*, 1995) uses *Dst* and the auroral boundary index (ABI) defined as the midnight equatorward boundary of the diffuse aurora at local midnight (*Gussenhoven et al.,* 1983). It also uses the magnetopause standoff distance as estimated from solar wind density and velocity measurements. The nightside magnetic field, especially near geosynchronous altitudes, becomes more distended or stretched as the ABI moves to lower latitudes. With magnetic field lines assumed to be lines of constant potential, the electric potential pattern is imposed on the equatorial simulation plane. Inductive electric fields affects are introduced implicitly through ionosphere-equatorial plane magnetic field line mapping changes.
>
> The electric field model incorporates a version of the Heppner-Maynard empirical model (*Heppner and Maynard*, 1987; *Rich and Maynard*, 1989) in the polar cap which is extended to lower latitudes using analytical methods based on more self-consistent modeling approaches (e.g., *Harel et al.*, 1981). It uses the polar cap potential drop, polar cap pattern type or interplanetary magnetic field (IMF), and the ABI. The ionospheric electric field strengthens as the polar cap potential increases and the electric potential pattern enlarges as the ABI moves to lower latitudes. An important dynamic feature is that the penetration of electric fields to sub-auroral latitudes is dependent on the rate of change of the ABI.
>
> The initial and time-dependent particle boundary conditions are controlled by *Kp* but boundary conditions are also modified according to the polar cap potential […]. Minimum and maximum particle flux levels assigned throughout the simulation region are enforced such that model output will fall within specified limits."

MSM Inputs

The MSM science module runs only in dynamic mode and thus requires the Global Parameters *Start: Year, Day, UT* and *End: Year, Day, and UT*. While the minimum run interval is only 15 minutes (900 s), in practice the simulation interval should be set to include the interval 3-6 hours before the actual period of interest to allow the initial dawn-dusk symmetric boundary conditions

to dissipate. Note that while the Global inputs Kp and SSN are used (F10.7 and Ap are not used), the MSM science module obtains those input values from an archived data set separate from the standard AF-GEOSpace global inputs (see the *Archive Input Data Files* section below). The MSM Options are as follows:

Run ID: User-created run identification (68 characters maximum). This descriptive character string is recorded in file *_msmin.dat* (where "_" represents the single letter *Run Prefix* described below) created in the MSM folder of the scratch space. It is suggested that users include the *Global: Start* and *End* times so that they can be reset when loading saved MSM runs.

Run Type: While two modes of MSM runs are possible, only one is currently implemented in this software release.

New Run: Indicates that a new MSM run is requested.

(Hot Restart): (not yet activated, future option will indicate that a previously completed MSM run will be continued or extended from a user-defined point)

Kp Mode: The MSM can be driven with different combinations of input parameters. Note that the Kp index is automatically used in all MSM runs and represents the default input set. The *Kp Mode* option offers three different modes of running the MSM:

Full MSM (Kp to fill gaps): This mode represents the most general way to run MSM and it allows the user to select from the complete set of available input parameters. If selected, an *MSM: Use Input* popup window will appear to register global parameter input preferences. Each data type will be used if entries exist within the chosen dynamic run interval. The geomagnetic index Kp is required to be available and is used to generate proxies for missing input data, to fill data gaps, and to drive internal parts of the MSM including boundary conditions. The file locations of the Kp values and parameter types listed here are given below in the *Archived Input Data Files* section. The addition input data types include:

DST: The Dst (disturbance storm time) hourly magnetic index in units of nT.

EQ Edge: The equatorward edge boundary of the diffuse aurora at midnight in degrees latitude in units of degrees latitude. (Also called the ABI above in the literature and EqE below when related to the *Show MSM Inputs* feature).

PCP: The polar cap potential input represents estimates of the total potential drop across the polar cap measured in kilovolts by the DMSP SSIES drift meter.

SWDEN, SWVEL: These options represent the solar wind density ($H+/cm^3$) and velocity (m/s), respectively. If selected, then the user must select a data source (*WIND* or *IMP8* spacecraft) and a resolution (*Hourly Averages* or *Hi Resolution (90 sec)*). Note: Owing to space limitation, only 1996 data provided (see below to obtain data for other years) and no *Hi Resolution (90 sec)* data is included with this release so the hourly values will always be used if the *SWDEN, SWVEL* option is selected.

Finally, the ionospheric electric field pattern is determined using one of three methods:

IMFBY, IMFBZ: The IMF B_y and B_z components in units of nT (from the *WIND* data set) are used to determine the value of *XIPATT* (see next entry) if no DMSP observations of the polar cap pattern are available. Note: Owing to space limitation, only 1996 data provided. See below to obtain data for other years.

XIPATT: The DMSP-derived potential pattern is used. The type of pattern used is listed after a run under the column labeled "P" via the *Show MSM Inputs* button. Pattern P=0 is for IMF-$B_z > 0$. For IMF-$B_z < 0$, the patterns correspond to IMF-$B_y <0$ (P=1), IMF-$B_y = 0$ (P=2), and IMF-$B_y>0$ (P=3). A negative sign indicates that the observation was derived from a DMSP southern hemisphere pass.

No IMF, XIPATT: Select if no specific method is desired. A default symmetric ionospheric electric field pattern is used.

Kp depend empir. flux output: This option skips the actual particle tracing portion of the MSM and fills the output files with Kp-dependent empirical flux values. Fluxes are distributed symmetrically about the noon-midnight plane in a manner similar to those used for the initial conditions.

Kp=> proxies for all input: This option represents the "Kp-Only" running mode of the MSM. The Kp index is the only required input parameter and all other input parameters are replaced by proxy values derived using the Kp-based relationships described by *Hilmer and Ginet* [2000].

Run Prefix: A single character selected by the user to define the run. This character is used as a file name prefix for many of the files created in the MSM folder in the scratch space.

(Static Inputs) The following parameters are either not currently activated or have fixed values for this implementation of the MSM program:

Last Record#: (not activated, relates to future *Run Type: Hot Restart*)

Start Record#: (not activated, relates to future *Run Type: Hot Restart*)

Act Start Time: (not activated, relates to future *Run Type: Hot Restart*)

Min Energy (keV): (Fixed) Minimum geosynchronous energy invariant to be tracked by the MSM. <u>Fixed equal to 0.030 keV</u>.

Max Energy (keV): (Fixed) Maximum geosynchronous energy invariant to be tracked by the MSM. <u>Fixed equal to 200 keV</u>.

Energy Spacing: (Fixed) Tracked geosynchronous invariant energies are spread equally by the <u>fixed value of 0.50</u> in log10(eV), i.e., MSM tracks particles of 10., 31.63, 100., 316.2, 1000., 3162., 10000., 31622., and 100000. eV (plus a 200000 eV ending value). Tracked values are selected from this set to span the *Min Energy* and *Max Energy* invariants.

PCP Factor: (Fixed) Factor used to adjust the DMSP-derived polar cap potential drop value. With algorithm improvements over the years, the current value is <u>fixed equal to 1.0</u>.

Species: The MSM offers the option to track electrons (*e-*), protons (*H+*), and oxygen (*O+*). For each species selected, the model tracks a set of particles at set invariant energies with values dependent on selections made from *Energy Range* and *L-Shell Range* options which follow. If those two options are not changed from their default values, then MSM will track 10 invariant energies for each species, giving a total of 30 species/energy pairs that the model can follow.

Energy Range (keV): *Low* and *High* particle energies defining range of interest (default setting and min/max range is 0.03 to 200 keV). Along with the *L-Shell Range* inputs below, these values are used to determine which invariant energies will be traced by the MSM.

L-Shell Range: *Low* and *High* L-shell range of interest (default setting and min/max range is 1.1 to 100 Re). In this context, the L-shell is basically the geocentric radial distance in the equatorial plane. Along with the *Energy Range* inputs above, these values are used to determine which invariant energies will be traced by the MSM.

Run Modes: This science module performs two basic functions which can be run consecutively or separately within AF-GEOSpace. The first function is called the *Base* run and represents input data collection and processing

plus the actually MSM simulation run over the user-defined dynamic interval. The second function maps particle fluxes from the generic MSM output file set on to the user-defined grid created within AF-GEOSpace using the *Edit* menu *Grid Tool* option. The mapping procedure uses the MAP3D and FLUX3D codes[4] and the magnetospheric neutral sheet-oriented coordinate system of *Hilmer* [1997].

Base/Map: Selecting this run mode will run the MSM simulation and populate the user-defined AF-GEOSpace output grid with particle fluxes for the species/energy pairs specified using the *Set Map Energies* button (below).

Base: Selecting this run mode will simply run the MSM simulation. In order to visualize the model output, the user must subsequently select the *Map* mode (below) and again use the *Run/Update* option of the *Edit* menu.

Map: Selecting this run mode will cause the software to look for an existing set of MSM run files corresponding to the *Run Prefix* entered. If the files are located in the *SciMsm* folder being used, then the mapping procedure is applied to populate the user-defined output grid with particle fluxes for the species/energy pairs specified using the *Set Map Energies* button (below). This option can be used to extract fluxes for different particle species/energies from an existing run of the current session or by loading results of a run saved during a previous session, i.e., load previously saved results with the *Open Model* option of the *File* menu, select different particle energies to map, and use the *Run Modes: Map* option so that the *Base* simulation will not be unnecessarily rerun.

Note: An MSM *Base* run does not need to be done if the user simply wants to map output from an existing run using either a modified grid or a different set of species/energy pairs. Simply make adjustments to the grid using the *Grid Tool* option of the *Edit* menu or adjust the species/energy pairs using the *Set Map Energies* button, then set *Run Modes = Map* and use the *Run/Update* option of the *Edit* menu. Remember that if you add a species/energy pair with the *Set Map Energies* button, then the corresponding entry of the *Dynamic Tool* of the *Edit* menu must be selected so that the new quantity will be written to file.

[4] Hilmer, R.V., Wolf, R.A., and Hausman, B.A., Mapping Magnetospheric Specification Model Results to Arbitrary Positions in the 3-D Magnetosphere: Development of FORTRAN Application Codes MAP3D and FLUX3D. Final Report for Hughes STX Corp. subcontract 93-F04-I1902, Rice University, Houston, TX (1993)

Check Modes: The *Check Modes* button provides a popup window with a run status summary indicating if a run with the currently selected *Run Prefix* already exists and providing a list of the available valid run options.

Show MSM Inputs: After an MSM run is complete, selecting this button produce a *Show Inputs* popup window containing the derived inputs used to drive the MSM at its 15-minute time steps. The values listed were derived by interpolation from the initial input parameter data sets. These derived numbers are from the file *_parameter* in the MSM folder in the scratch space. In order to produce 15-minute Kp values and avoid a step-like change in the parameters, that Kp is transitioned gradually each 3 hours. This is done because the MSM electric field model uses the time-rate-of-change of Kp. If available, the values for Dst, EqE, PCP, IMFBY, IMFBZ, SWDEN, and SWVEL are all determined via interpolation. The magnetopause standoff distance (Std) is derived via a Kp relationship if SWDEN and SWVEL are not available. The column labeled “P” refers to the polar cap potential pattern type XIPATT described above.

Set Map Energies: The *Set Map Energies* button activates the *MSM Energies* popup window used set the particles energies to be processes for viewing with the graphics modules. The user may enter up to five energies (in keV) per active species where active species are those checked in the main MSM environment window, i.e., *e-, H+,* and *O+*. By default, the *MSM Energies* window is set such that only 30 keV electrons will be tracked. For a given species/energy pair to be available for plotting, the corresponding entries in the *Dynamic Tool* of the *Edit* menu must be selected (see next note).

Note: To visualize all user-designated species/energy pairs selected using the *Set Map Energies* button, the *Dynamic Tool* of the *Edit* menu for an active MSM science module must be set to write the appropriate quantities to file. The MSM *Dynamic Tool* window entries *eEnergy0* to *eEnergy4* correspond to the *e- Energy (keV)* entries *0*-to-*4* in the *MSM Energies* window. Similarly, the *Dynamic Tool* entries *hEnergy0* to *hEnergy4* correspond to the *H+ Energy (keV)* entries *0*-to-*4* and the entries *oEnergy0* to *oEnergy4* correspond to the *O+ Energy (keV)* entries *0*-to-*4*. In addition, if the GSM X, Y, Z, and total magnetic field values (*Bx, By, Bz*, and *Btot*) from the MSM are to be plotted then they must also be selected in the *Dynamic Tool*.

Required Library Files

The mapping procedure used to fill AF-GEOSpace grids with MSM output is from *Hilmer et al.* [1993] and includes updates related to the location of the magnetotail neutral sheet as described by *Hilmer* [1997]. The following library files are required to run the MSM and map results (Note: the “*” represents a variety of numeric character strings).

$AFGS_HOME\models\data\MSM\BMATRIX – *bo3*.dat* (1864 files, 350 MB)

$AFGS_HOME\models\data\MSM\TBLMAT – *TBL*.DAT*, *MAT*.DAT* (1864 files, 1.16 GB)

$AFGS_HOME\models\data\MSM – static files *COORD, DKTABLE, EFCOEF, HARDY, IONENG*, and *IONNUM*

Archived Input Data Files

The following input data files are provided for running the MSM. Input data used to drive the MSM are archived in a separate location from the parameters used by the rest of the software (i.e., the Global Parameters described in the ENVIRONMENT section of this document). For details on the input data types used to drive the MSM and a description of proxy values determined using the Kp index please see section 5 of *Hilmer and Ginet* [2000]. Note that additions to the archive must be done manually as no automatic updates are available. Editing and saving data values via the *Show* option of the *Globals* menu does not change the inputs used by MSM. In the following descriptions the characters "*YYYY"* indicate the calendar year.

$AFGS_HOME\models\data\MSM\PARAMS contains directories:

DST: Hourly Dst index from files *dstYYYY* for years 1957-2012 (May). These files match those supplied via $AFGS_HOME\models\data\GLOBALS\DST and can be updated by the user in the same manner. Source: NGDC at website ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/DST/. See the file *00info_DST* for format details.

KP_AP: Three-hour Kp index and SumKp value from files *kpYYYY* for years 1932-2012 (April). These files match those in $AFGS_HOME\models\data\GLOBALS\KP and can be updated by the user in the same manner. Source: NGDC at website ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP/. See the file *00info_KP_AP* for format details.

$AFGS_HOME\models\data\MSM\SPACECRAFT\DMSP contains directories:

SSJ4\MEB: Midnight equatorward boundary values (for *Eq. Edge*) for 1983 to day 104 of 2010 from files *mnitYYYY.new*. Source: AFRL (Dan Madden and F. J. Rich). See the file *00info_MEB* for details.

SSIES\PCSHRT: Cross-polar cap potential (for *PCP*) and electric field pattern type (for *XIPATT*) for years 1987-2004 from DMSP data files *sDDYYYY.txt* where *DD* is the DMSP satellite number 08, 10, 11,12, or 13. See the file *00info_PCSHRT* for details.

$AFGS_HOME\models\data\MSM\SPACECRAFT contains directories:

IMP8: Hourly solar wind velocity (for *SWVEL*), density (*SWDEN*), temperature from file *imp8.1996.hravg.subset*. Files for other years can be obtained from the MIT website ftp://space.mit.edu/pub/plasma/imp/hr_avg/. See the file *00info_IMP8* for format details. [Acknowledgements: A.J. Lazarus, P.A. Milligan, and K.I. Paularena (all of MIT)]

WIND: Hourly IMF (for *IMFBY, IMFBZ*) from files *1996_wnd_mfi.asc* and solar wind velocity and density from files *1996_WIND_hourly_averages*. See the file *00info_WIND* for format details. Files for other years can be obtained from the MIT website ftp://space.mit.edu/pub/plasma/wind/kp_files_hr_aves/.

[Acknowledgements: Principal Investigator K.W. Ogilvie (NASA GSFC), A.J. Lazarus (MIT) and J.C. Kasper (MIT)]

Before each MSM run, input data falling within the simulation interval are time sorted and rewritten to create the actual MSM input data files (i.e., DST, EQEDGE, FKP, IMFBY, IMFBZ, PCP, SWDEN, SWVEL, SUMKP, and *XIPATT*) that are recorded in the *SciMsm* directory in the user's scratch space. The *Show MSM Inputs* button can be used to view the parameters finally used to drive the MSM at15-minute time steps.

Notes on the MSM Run Procedure

For a detailed description of an MSM simulation using this module, please see "Magnetospheric Specification Model" in the EXAMPLES section of this document.

<u>Quick-Start Procedure</u>: The default MSM module run setup will produce output for 30 keV electrons using the Kp Mode option *Kp=>proxies for all input* (also known as the "Kp-Only" mode). To run in this simplest of modes, the user must (1) open an AF-GEOSpace session, (2) establish a dynamic run by placing a check mark in the box to the right of the *Start:UT* text field and completing the *Start* and *End* time fields, and (3) use the *Run/Update* option of the *Edit* menu. The software will read Kp indices from the archived data directories described above, run the MSM simulation, and fill the grid (see the *Grid Tool* option of the *Edit* menu) with 30 keV electron flux values.

Note: If no environment data is available (not even Kp) then a popup message will appear indicating "ERROR: NTLINE=0, *global.dat* file empty". In the *SciMsm* folder created at run time, see the file *global.inf* for a summary of data sources, quantities available, and names of other files with more details. The file *dbg.txt* shows what the session looks like running in FORTRAN and the contents of newly created files *ENCHAN* and *_msmin.dat* are repeated there.

MSM Outputs

The MSM science module returns a 3D Gridded Data set of the following magnetospheric quantities: electron (e-), proton (H+), and oxygen (O+) particle fluxes in units of Log[#/cm2-s-keV-ster], and magnetic field values for GSM components Bx, By, Bz, and |B| in units of nT. Note that particles of a given species/energy will be found in a limited region of the magnetosphere and that, in general, the more energetic particles will be found closer to Earth. Otherwise, if no particle flux information is given at a specific grid location for an energy set using the *Set Map Energies* button, then either (a) the grid point is outside of the MSM simulation region, or (b) that particle energy was not covered by the geosynchronous invariant energy channels calculated with the user-selected *Species: Energy Range (keV)* and *L-Shell Range* values.

The NASAELE Science Module

Model Name: NASA Trapped Electron Model AE-8

Version: National Space Science Data Center (NSSDC) Data Set PT-11B, Oct 1987; IGRF updates 2009

Developer: NASA/NSSDC (distributed in AF-GEOSpace with permission); IGRF option updates by AER, Inc.

References: Vette, J.I., The AE-8 Trapped Electron Model Environment, *NSSDC/WDC-A-RS 91-24* (1991)

Vette, J.I., The NASA/National Space Science Data Center Trapped Radiation Environment Model Program (1964-1991), *NSSDC/WDC-A-RS 91-29* (1991)

Jordan, C.E., NASA Radiation Belt Models AP-8 and AE-8, *GL-TR-89-0267*, Geophysics Laboratory, Hanscom AFB, MA (1989), ADA 223660

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

NASAELE Overview

The NASAELE science module computes the differential omni-directional electron flux using the NASA AE-8 radiation belt models for ten energy intervals between 0.5 and 6.6 MeV which correspond to the ranges of the CRRES HEEF instrument data channels used in the construction of the CRRESELE science module. Two additional channels are computed that represent the energy ranges 0.04-0.5 MeV and 6.6-7 MeV covered in the NASA models but not covered by the HEEF instrument. The following NASA radiation belt models description is excerpted from the on-line summary and instructions available at the anonymous ftp site NSSDCA.GSFC.NASA.GOV:

> “[The NASA radiation belt] models describe the differential or integral, omni-directional fluxes of electrons (AE-8) and protons (AP-8) in the inner and outer radiation belts (electrons: L=1.1 to 11, protons: L=1.1 to 7) for two epochs representing solar maximum (1970) and minimum (1964) conditions. The energy spectrum ranges from 0.1 to 400 MeV for the protons and from 0.04 to 7 MeV for the electrons. AE-8 and AP-8 are the most recent ones in a series of models established by J. Vette and his colleges at NSSDC starting in the early sixties. The models are based on almost all available satellite data”.

The NASAELE science module is used to map the NASA AE-8 electron flux models for either solar maximum (AE8MAX) or minimum (AE8MIN) conditions onto a three-dimensional spatial grid specified by the user. A variety of magnetic field models can be used for the mapping.

NASAELE Inputs

The NASAELE science module requires the user to specify the following information to determine which data set to use and which magnetic field model to use in mapping the data,

Energy Channel(MeV): The energy channel parameter specifies which of 10 electron flux models, corresponding to the 10 HEEF instrument energy channels used in

the CRRESELE models, is to be used. The channels used for the CRRESELE models are to be considered. The channels span the range from 0.5-6.6 MeV. Two additional channels are included spanning the ranges above (6.6-7.0 MeV) and below (0.04-0.5 MeV) the HEEF channels covered by the NASA models.

B-Model: The magnetic field model used to convert from the B-L coordinates of the model to three-dimensional space. Originally and as presented in AF-GEOSpace Version 2.1, the default magnetic field was the model used to reduce the CRRES data, i.e., *IGRF85/O-P*. However, after including time-dependent IGRF internal field capabilities covering 1945-2010, the current *B-Model* options include:

- Dipole: A dipole field
- Dipole-Tilt: A tilted dipole field
- Dip-Tilt-Off: A tilted-offset dipole field
- IGRF: The International Geomagnetic Reference Field with no external contributions (Extrapolation beyond 2010).
- IGRF/O-P: The *IGRF* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.

Activity: The activity parameter specifies whether the *AE8MAX* (representative of solar maximum conditions) or the *AE8MIN* (representative of solar minimum conditions) electron flux models are to be used.

NASAELE Outputs

The NASAELE science module returns a 3D Gridded Data Set of the electron flux for the selected energy channel and activity level in units of #/(cm^2 s keV).

The NASAPRO Science Module

Model Name: NASA Trapped Proton Model AP-8

Version: National Space Science Data Center (NSSDC) Data Set PT-11B, Oct 1987; IGRF updates 2009

Developer: NASA/NSSDC (distributed in AF-GEOSpace with permission); IGRF option updates by AER, Inc.

References: Vette, J.I., The AE-8 Trapped Electron Model Environment, *NSSDC/WDC-A-RS 91-24* (1991)

Vette, J.I., The NASA/National Space Science Data Center Trapped Radiation Environment Model Program (1964-1991), *NSSDC/WDC-A-RS 91-29* (1991)

Jordan, C.E., NASA Radiation Belt Models AP-8 and AE-8, *GL-TR-89-0267*, Geophysics Laboratory, Hanscom AFB, MA (1989), ADA 223660

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

NASAPRO Overview

The NASAPRO science module computes the differential omni-directional proton flux using the NASA AP-8 radiation belt models for twenty-two energy intervals between 1 and 100 MeV which correspond to the ranges of the CRRES PROTEL instrument channels used in the construction of the CRRESPRO science module. [Note that Version 2.1 computed two additional channels that represented the energy ranges 0.1-1.0 MeV and 100-400 MeV covered in the NASA models but not covered by the PROTEL instrument.] The following NASA radiation belt models description is excerpted from the on-line summary and instructions available at the anonymous ftp site NSSDCA.GSFC.NASA.GOV:

> "[The NASA radiation belt] models describe the differential or integral, omni-directional fluxes of electrons (AE-8) and protons (AP-8) in the inner and outer radiation belts (electrons: L=1.1 to 11, protons: L=1.1 to 7) for two epochs representing solar maximum (1970) and minimum (1964) conditions. The energy spectrum ranges from 0.1 to 400 MeV for the protons and from 0.04 to 7 MeV for the electrons. AE-8 and AP-8 are the most recent ones in a series of models established by J. Vette and his colleges at NSSDC starting in the early sixties. The models are based on almost all available satellite data".

The NASAPRO science module is used to map the NASA AP-8 proton flux models for either solar maximum (AP8MAX) or minimum (AP8MIN) conditions onto a three-dimensional spatial grid specified by the user. A variety of magnetic field models can be used for the mapping.

NASAPRO Inputs

The NASAPRO science module requires the user to specify the following information to determine which data set to use and which magnetic field model to use in mapping the data,

Energy Channel(MeV): The energy channel parameter selects which of 22 proton flux models, corresponding to the 22 PROTEL instrument energy channels used in the

construction of the CRRESPRO models, is to be used. The channels range from 1.5 to 81.3 MeV. Two additional channels are included spanning the ranges above (100 to 400 MeV) and below (0.1 to 1.0 MeV) the PROTEL channels covered by the NASA models.

B-Model: The magnetic field model used to convert from the B-L coordinates of the model to three-dimensional space. Originally and as presented in AF-GEOSpace Version 2.1, the default magnetic field was the model used to reduce the CRRES data, i.e., *IGRF85/O-P*. However, after including time-dependent IGRF internal field capabilities covering 1945-2010, the current *B-Model* options include:

Dipole:	A dipole field
Dipole-Tilt:	A tilted dipole field
Dip-Tilt-Off:	A tilted-offset dipole field
IGRF:	The International Geomagnetic Reference Field with no external contributions (Extrapolation beyond 2010).
IGRF/O-P:	The *IGRF* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.

Activity: The activity parameter specifies whether the *AP8MAX* (representative of solar maximum conditions) or the *AP8MIN* (representative of solar minimum conditions) proton flux models are to be used.

NASAPRO Outputs

The NASAPRO science module returns a 3D Gridded Data Set of the proton flux for the selected energy channel and activity level in units of #/(cm^2 s MeV).

The NRLMSISE-00 Science Module

Model Name:	NRLMSISE-00 Model 2001
Version:	Official release file NRLMSISE-00.DIST17.TXT obtained from http://uap-www.nrl.navy.mil/models_web/msis/msis_home.htm.
Developer:	J. M. Picone, A.E. Hedin, and D.P. Drob, Navel Research laboratory
References:	Hedin, A.E., MSIS-86 Thermospheric Model, *J. Geophys. Res. 92*, 4649 (1987)
	Hedin, A.E., Extension of the MSIS Thermospheric Model into the Middle and Lower Atmosphere, *J. Geophys. Res., 96*, 1159 (1991)
	Jacchia, L., New Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles, *Spec. Rep., 313*, Smithsoni. Astrophys. Observ., Cambridge, Mass., May 6 (1970)
	Labitzke, K., J.J. Barnett, and B. Edwards (eds.), Handbook MAP 16, SCOSTEP, University of Illinois, Urbana (1985)
	Picone, J.M., A.E. Hedin, D.P Drob, and A.C. Aikin, NRLMSISE-00 Empirical Model of the Atmosphere: Statistical Comparisons and Scientific Issues, *J. Geophys. Res., 107*(A12), 1468, doi:10.1029/2002JA009430 (2002)

Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

NRLMSISE-00 Overview

The NRLMSISE-00 model provides a description of the atmosphere as a function of location, time, solar activity (F10.7), and geomagnetic activity (Ap). NRLMSISE-00 models altitude profiles of temperature *T(z)*, the number density of various species (i.e., He, O, N_2, O_2, Ar, H, and N) that are in equilibrium with temperature *T(z)*, the total mass density, and the number density of a high-altitude “anomalous oxygen” component not in equilibrium at *T(z)* [*Picone et al.*, 2002]. These authors also note that the NRLMSISE-00 empirical atmospheric model is a major upgrade of the MSISE-90 thermosphere model of *Hedin* [1991] and for estimating total mass density, it is comparable to or better than the Jacchia-class models (e.g., see *Jacchia* [1970]). Below 72.5 km, the MSISE-90 model is primarily based in the *Labitzke et al.* [1985] tabulation of zonal average temperature and pressure. Above 72.5 km, MSISE-90 is basically a revised MSIS-86 model [*Hedin*, 1987]. Note that for user only interested in the thermosphere (above 120 km), the authors recommend the MSIS-86 model. As noted on the NSSDC website referenced above, the upgrade from MSISE-90 to NRLMSISE-00 involves (1) extensive use of drag and accelerometer data on total mass density, (2) the addition of contributions from O+ and hot oxygen at altitudes above 500 km, and (3) the inclusion of Solar Maximum Mission UV occultation data on 0_2 number density. The code is also made available, along with many other related links, by NSSDC at (http://nssdc.gsfc.nasa.gov/space/model/atmos/nrlmsise00.html).

NRLMSISE-00 Inputs

The NRLMSISE-00 science module requires the following inputs,

Global Parameters: Day, UT, F10.7, and Ap (Year, Kp, and SSN are not used).

10.7 cm Radio Flux for the previous day: Daily average solar radio flux at 10.7 cm for the previous day (*F10.7P*) can be determined two ways.

From Globals: The program assigns *F10.7P* a value equal to F10.7 for the previous day as noted in the global parameter files.

Set: If selected, the program uses the value entered in the newly activated text window *F10.7P*.

81-day Average (+/- 40 days) 10.7 cm Radio Flux: This input is the 81-day average (including +/- 40 days from day of interest) of F10.7 daily values (*F10.7A*) and can be determined two ways.

From Globals: The program assigns *F10.7A* a value equal to the average determined using the global parameter files. As noted above, the last valid run day is the day before the last day listed in the Kp data files (which contain daily F10.7 values). If a valid day is selected, then the average is constructed using the previous 40 days plus any available forward data, with the last good day repeated to fill out the required forward 40-day span.

Set: If selected, the program uses the value entered in the newly activated text window *F10.7A*.

Notes: (1) The next day's F10.7 value is needed for a successful run (see *F10.7A* description above), thus the last valid day to run the model is the day before the last day listed in the Kp data files (see directory $AFGS_HOME\models\data\GLOBALS\KP).

(2) While the model uses the global parameter F10.7, it does not use the single value appearing at the top of the environment window.

(3) As noted in the *Model Status* box after a run, this installation of the model substitutes the 3-hour Ap index value for the Daily Ap index it expects as input, i.e., the user can specify the Daily Ap value used by the model by editing the Ap text box at the top of the environment window.

(4) For dynamic runs, the values of *F10.7P* and *F10.7A* determined for the start day will be used unchanged for the entire run interval.

NRLMSISE-00 Outputs

The NRLMSISE-00 science module returns a 3D Gridded Data Set of the following quantities:

HE Number Density: Helium (He) number density (cm^{-3}).

O Number Density: Atomic oxygen (O) number density (cm^{-3}). Set to zero below 72.5 km.

N2 Number Density: Molecular nitrogen (N_2) number density (cm^{-3}).

O2 Number Density:	Molecular oxygen (O_2) number density (cm^{-3}).
AR Number Density:	Argon (Ar) number density (cm^{-3}).
Total Mass Density:	Total mass density (g/cm^3).
H Number Density:	Atomic hydrogen (H) number density (cm^{-3}). Set to zero below 72.5 km.
N Number Density:	Atomic nitrogen number density (cm^{-3}). Set to zero below 72.5 km.
anO Num. Density:	Anomalous oxygen number density (cm^{-3}). Anomalous oxygen refers to hot atomic oxygen (O_h) or atomic oxygen ions (O^+) present at high altitudes (> 500 km) that are not in thermal equilibrium.
T Exospheric:	Exospheric temperature (Degrees K).
T at Alt:	Temperature (Degrees K).

For 1D vertical profile displays, we recommend increasing the default number of radial points calculated (using the *Grid Tool* option of the *Edit* menu) and displaying a COORD-PROBE graphical object in a 1D Viewport. For 2D or 3D displays, use the COORD-SLICE graphical object. To examine output along an orbit run the SATEL-APP application followed by the ORBIT-PROBE graphical object.

The PIM Science Module

Model Name:	Parameterized Ionospheric Model (PIM)
Version:	1.7 (16 December 1999)
Developer:	Computational Physics, Inc. and Air Force Research Laboratory
References:	Daniell, R.E., Jr., L.D. Brown, D.N. Anderson, M.W. Fox, P.H. Doherty, D.T. Decker, J.J. Sojka, and R.W. Schunk, Parameterized Ionospheric Model: A Global Ionospheric Parameterization Based on First Principles Models, *Radio Sci., 30,* 1499-1510 (1995)
	Strickland, D.J., J. E. Bishop, J. S. Evans, T. Majeed, P. M. Shen, R. J. Cox, R. Link, and R. E. Huffman, Atmospheric ultraviolet radiance integrated code (PIM): theory, software architecture, inputs, and selected results, *J. Quant. Spect. Rad. Transfer, 62*, 689 (1999)
	Computational Physics, Inc., PIM 1.7 User Guide, 13-January-1998 (see $AFGS_HOME\models\REFS\pim17ug.pdf)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

PIM Overview

The PIM science module is a relatively fast global ionospheric model based on the combined output of several physical ionospheric models. The following description of PIM is excerpted from *Daniell et al.* (1995),

> "[The Parameterized Ionosphere Model (PIM)] is a global model of theoretical ionospheric climatology based on diurnally reproducible runs of four physics-based numerical models of the ionosphere. The four models, taken together, cover the E and F layers for all latitudes, longitudes, and local times. PIM consists of a semi-analytic representation of diurnally reproducible runs of these models for low, moderate, and high levels of solar and geophysical activity and for June and December solstices and March equinox conditions."

From a user-specified set of geophysical parameters, including year, day, UT, solar activity index F10.7, sunspot number, geomagnetic activity index Kp, and the directions of the interplanetary field components By and Bz, the PIM science module computes values of the electron density on a user-specified 3D grid. The range in altitude is 90 to 1600 km. Also computed by PIM and output on 2D grids are the height-independent critical frequencies and heights for the ionospheric E- and F2-regions (FoE, HE, FoF2, and HF2) as well as the Total Electron Content (TEC).

PIM Inputs

The PIM science module requires the following inputs:

Global Parameters:	Year, Day, UT, Kp, SSN, and F10.7. Either SSN or F10.7 can be omitted if the appropriate *F10.7/SSN* option is chosen as discussed below.

F2 Model Norm: This option tells PIM whether to normalize the critical frequency of the ionospheric F2-layer (FoF2).

None: No FoF2 normalization is performed.

URSI: FoF2 normalization is performed using the URSI global empirical model.

E Model Norm: This option tells PIM whether to normalize the critical frequency of the ionospheric E-layer (FoE).

None: No FoE normalization is performed.

Empirical: FoE normalization is performed using a semi-empirical model.

IMF By: The orientation of the Y-component of the interplanetary magnetic field may be set to *Positive* or *Negative*.

IMF Bz: The orientation of the Z-component of the interplanetary magnetic field may be set to *Positive, Zero*, or *Negative*.

F10.7/SSN: The relationship between the instantaneous F10.7 cm solar radio flux and the sun spot number can be set several ways, namely

Decoupled: The sun spot number and solar radio flux will be treated as independent quantities.

F10.7->SSN: The sun spot number will be estimated from the solar radio flux.

SSN->F10.7: The solar radio flux will be estimated from the sun spot number.

Write to File: Specifies the base file name that the PIM results should be stored in.

Ext: The *Ext* option must be selected if electron densities are generated in dynamic mode and if RAYTRACE-APP is to be used to trace a set of rays at each time step, i.e., selecting this option will create a series of files (with the base file name specified above) with sequentially numbered extensions.

PIM Outputs

PIM returns the spatial distribution of the following ionospheric quantities,

Elec. Density: The electron density ($\#/cm^3$) is returned as a 3D Gridded Data Set.

FoE: The critical frequency (MHz) of the E layer of the ionosphere is returned as a 2D Gridded Data Set in latitude and longitude.

HE: The altitude (km) of the peak of the ionospheric E layer is returned as a 2D Gridded Data Set in latitude and longitude.

FoF2: The critical frequency (MHz) in the F2 layer of the ionosphere is returned as a 2D Gridded Data Set in latitude and longitude.

HF2: The altitude (km) of the peak of the ionospheric F2 layer is returned as a 2D Gridded Data Set in latitude and longitude.

TEC: The total electron content (height integrated electron density in units of 10^{12} cm^{-2}) is returned as a 2D Gridded Data Set in latitude and longitude.

The PPS Science Module (V2.5.1 and Static Only)

Model Name:	Proton Prediction System (PPS)
Version:	96
Developer:	D. Smart and M. Shea, Air Force Research Laboratory
References:	Kahler, S.W., E.W. Cliver, and A.G. Ling, Validating the Proton Predition System (PPS), *J. Atmos. Solar-Terr. Phys., 69*, 43-49 (2007) [see file $AFGS_Home\models\REFS\KahlerCliverLing2007.pdf]
	Smart, D.F., and M.A. Shea, PPS76 - A Computerized "Event Mode" Solar Proton Forecasting Technique, in *Solar Terrestrial Predictions Proceedings*, edited by R.F. Donnelly, U.S. Department of Commerce, *NOAA/ERL, 1*, p. 406 (1979)
	Smart, D.F., and M.A. Shea, PPS-87: A New Event Oriented Solar Proton Prediction Model, *Adv. Space Res., 9*, No. 10, (10)281-(10)284, (1989)
	Smart, D.F., and M.A. Shea, Modeling the Time-Intensity Profile of Solar Flare Generated Particle Fluxes in the Inner Heliosphere, *Adv. Space Res., 12*, No. 2-3, (2)303-(2)313, (1992)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

PPS Overview

The PPS Science module is based on the Proton Prediction System (PPS) software program[5] developed by the Air Force Research Laboratory. Previous versions for DOS PCs have been released. As *Smart and Shea* (1979) explain:

> "[PPS] has been developed to generate a computerized time-intensity profile of the solar proton intensity expected at the Earth after the occurrence of a significant solar flare on the sun. This procedure is a combination of many pieces of independent research and theoretical results. It is not a comprehensive self-consistent analytical method, but is a construction of selected experimental and theoretical results from the entire domain of solar-terrestrial physics."

PPS has been constructed to model protons that are accelerated during energetic solar events (i.e., those associated with flares) near the solar surface. It does NOT model proton acceleration that might occur in an interplanetary shock propagating towards the Earth. Most proton events at Earth are the result of protons accelerated near the solar surface. "Hybrid" solar flare-interplanetary shock accelerated events occur on the order of a dozen times during a solar cycle. While such hybrid events are infrequent, they can be quite large.

[5] Preliminary Software User's Manual for the Proton Prediction System, Critical Design Review Data Package for the Proton Prediction Model, Prepared by C. B. Tang, Inc for contract no. F19628-87-C-0044, March (1987)

The PPS system is designed to generate a solar proton flux distribution in space that will match the Earth-observed statistical average intensity-time profile, flux and time-of-maximum spectra found by spacecraft measurements to be associated with solar activity at a specific helio-longitude with respect to the Earth.

The solar proton flare event diagnostics of the 1970's and 1980's are identical to the fast CME proxies of the 1990's. The concept of particle acceleration in the solar corona by fast CME's is still consistent with the fundamental parameters of the Proton Prediction system. It is assumed that the maximum possible flux will be encountered on the Archimedean spiral path leading from the solar active region. It is also assumed that there is a relation between the energy in the electromagnetic emission parameters and the proton flux observed in space. It is further assumed that there will be a helio-longitudinal gradient of particle intensity in space that decreases one order of magnitude per radian of angular separation for the most favorable propagation path. The particle flux intensity in space will be mapped in accordance with the Archimedean spiral configuration of the interplanetary magnetic field. The connection of the Earth to the solar active region via the interplanetary magnetic field is a controlling parameter in the prediction of how much solar particle flux will be received at the Earth.

The PPS system is designed to take many input parameters. The first available reports of intense radio or solar X-ray emissions, from onset to maximum, can be utilized for a quick prediction mode. This allows for a possible prediction of the solar proton event before the solar protons reach the Earth. Unfortunately, this quick prediction mode based on peak flux data is also the least accurate. The PPS prediction accuracy essentially doubles when event integrated data are used for the input.

The input needed to specify the time and intensity of the solar flare source in the PPS can take two forms: (a) solar radio emissions observed by the USAF RSTN sites at 8800, 4995, 2695, 1415, 606 MHz or 10 cm (b) soft X-ray events observed by the GOES satellites in either the 0.5-4.0 or 1-8 Angstrom bands. The location of the solar flare is determined from H-alpha observations made by the USAF SOON sites. PPS contains an "expert" mode enabling the user to override certain PPS default values used to classify the proton energy spectra at the Earth, but its use is NOT recommended unless the user has considerable experience in interpreting solar proton events.

The version of PPS implemented in AF-GEOSpace provides output showing the time dependence of proton fluxes in several differential and integral energy channels relevant to the GOES satellite. Also given are the time intervals for which the > 5 MeV, > 10 MeV and > 50 MeV integral proton fluxes, such as measured on the GOES satellites, are above the threshold value of 10 particles/(cm^2-s-sr). The time and value of the peak response in each of the above channels during the solar proton event is estimated. Several user-specific quantities are also calculated including forecasts for the riometer absorption in Thule, Greenland, maximum radiation dosage for pilots in high-flying aircraft above the poles, and maximum radiation dosage to be expected both inside and outside a polar-orbiting space shuttle.

PPS Inputs

The PPS science module requires the following inputs:

Global Parameters: Year, Day, UT (used to initialize event onset time and time of maximum)

Specify Data: The user can choose whether solar *X-Ray* emissions as measured by the GOES satellite or solar *Radio* emission data as measured by the USAF RSTN sites are to be used to parameterize the solar flare.

Specify Flux Type: The user chooses whether *Peak Flux* or *Integrated Flux* values are to be used to characterize the amplitude of the *X-Ray* or solar *Radio* emissions.

X-ray Data: If *X-Ray* is chosen as the data type (and *Use X-ray classification input* is not selected), the user chooses whether to use either the *0.5 - 4.0 Angstrom* or *1.0 - 8.0 Angstrom* bands.

Radio Frequency: If *Radio* is chosen as the data type, the user selects which fixed frequency band, centered at *8800, 4995, 2695,* or *1415* MHz*,* is to be used.

Event Onset Time: Depending on the choice of data type, the onset time of either the radio or X-ray event in the format MM/DD/YY HH:MM.

Time of Maximum: Depending on the choice of data type, the time of the maximum amplitude of either the radio or X-ray event in the format MM/DD/YY HH:MM.

Flare lat (deg N): The solar latitude, in degrees North, of the solar flare associated with either the X-ray or radio event. This information can be obtained from H-alpha observations by the USAF SOON sites. Degrees South are entered as negative numbers.

Flare lon (deg W): The solar longitude, in degrees West, of the solar flare associated with the X-ray or radio event. This information can be obtained from H-alpha observations by the USAF SOON sites. Degrees East are entered as negative numbers.

Use X-ray classification input?: If *X-Ray* is the input data type and *Peak Flux* is the flux type, the user can select here whether to use the standard X-ray event classification scheme to specify the magnitude of the peak.

Peak class.: If the *X-Ray* classification type is used to specify the peak magnitude of an X-ray event, the user enters the peak X-ray level measured by either the 0.5-4.0 or 1-8 Angstrom (depending on the X-ray band selected above) X-ray instrument on the GOES satellites. These values are entered with a classification letter and a numeric field. The usual X-ray event classification letters C, M, and X are used with a numeric field to multiply the flux level. The range of allowed values is C1.0 through X99.0.

"Event amplitude": The descriptor for this text box changes depending on what options for input data have been selected. The beginning of the line plainly states the type of input data required and what units need to be used, that is,

Peak X-Ray = Peak X-ray emission in units of ergs/cm^2/s (if the X-ray classification option has not been selected).

Integ. X-Ray = Integrated X-ray emission in units of Joules/cm$^{2.}$

Peak Radio = Peak Radio emission in Solar Flux Units (=1.0 x 10^{-22} W/m^2 Hz)

Integ. Radio = Integrated Radio emission in units of SFU-s

The six character code at the end of the descriptor line summarizes the input and has the following format: AAANNB, where,

AAA = XRY if *X-Ray* has been selected as the input data type

RAD if *Radio* has been selected as the input data type

NN = 54 if the *0.5-4.0* Angstrom X-Ray data band has been chosen

18 if the *1.0-8.0* Angstrom X-Ray data band has been chosen

14 if the *1415* MHz Radio Frequency has been chosen

26 if the *2695* MHz Radio Frequency has been chosen

49 if the *4995* MHz Radio Frequency has been chosen

88 if the *8800* MHz Radio Frequency has been chosen

B = P if the *Peak Flux* has been chosen

I if the *Integrated Flux* has been chosen

Amplitude data can be entered in the standard integer, real number, or exponential formats

Expert Mode: This mode allows the user to override certain PPS default input quantities, i.e., spectral slope, spectra type (differential or integral), flux normalization, time of flux maximum, and GOES energy channel.

Note: Use of the *Expert Mode* is NOT recommended unless the user has considerable experience in interpreting solar proton events.

The remainder of the buttons in the PPS environment window control various output options and are described below.

PPS Outputs

PPS returns a text message window containing the results of the model calculations and a summary of the input parameters. The model provides the following predictions:

- Maximum day polar riometer absorption at Thule, Greenland, in db, and the time that this maximum will occur in HH:MM (UT) MON DD. This prediction is valid if it is daytime at Thule (i.e., between 6:00 and 18:00 LOCAL Thule time) during the interval of the solar event. Note that ionospheric absorption is a function of the solar zenith angle.
- Maximum night polar riometer absorption at Thule, Greenland, in db, and the time that this maximum will occur in HH:MM (UT) MON DD. This prediction is valid if it is nighttime at Thule (i.e., between 18:00 and 6:00 LOCAL Thule time) during the interval of the solar event.
- Maximum dose rate expected at an altitude of 70,000 feet above the polar regions, in mRad/hr, and time this maximum will occur in HH:MM (UT) MON DD. This output can be used to estimate pilot dosages.

- Maximum dose rate expected at an altitude of 50,000 feet above the polar regions, in mRad/hr, and time this maximum will occur in HH:MM (UT) MON DD. This output can be used to estimate pilot dosages.
- Maximum dose rate above the polar regions at altitudes corresponding to typical space shuttle orbits (about 250 km). Dose rates in Rad/hr are given for both Extra Vehicular Activities (no shielding) and inside the shuttle behind 2 g/cm^2 of Aluminum shielding. The time of maximum is also given in HH:MM (UT) MON DD.
- The interval of time for which the > 5 MeV proton flux near Earth (e.g., as measured on the GOES satellites) will be above the threshold value of 10 particles/(cm^2-s-sr) in the form MON DD HH:MM (UT, start time) - MON DD HH:MM (UT, end time). The maximum flux value, in particles/(cm^2-s-sr), and the time of the maximum in HH:MM (UT) MON DD are given. Also estimated is the > 5 MeV fluence (= flux*time) for the duration of the event.
- The interval of time for which the > 10 MeV proton flux near Earth (e.g., as measured on the GOES satellites) will be above the threshold value of 10 particles/(cm^2-s-sr) in the form MON DD HH:MM (UT, start time) - MON DD HH:MM (UT, end time). The maximum flux value, in particles/(cm^2-s-sr), and the time of the maximum in HH:MM (UT) MON DD is given. Also estimated is the > 10 MeV fluence (= flux*time) for the duration of the event.
- The interval of time for which the > 50 MeV proton flux near Earth (e.g., as measured on the GOES satellites) will be above the threshold value of 10 particles/(cm^2-s-sr) in the form MON DD HH:MM (UT, start time) - MON DD HH:MM (UT, end time). The maximum flux value, in particles/(cm^2-s-sr), and the time of the maximum in HH:MM (UT) MON DD is given. Also estimated is the > 50 MeV fluence (= flux*time) for the duration of the event.

PPS also provides three plots selectable from buttons in the PPS Environment window:

Diff Flux-GOES: Differential proton flux as a function of time at geosynchronous altitude for the energy ranges measured by the Space Environment Monitor on the GOES satellites, i.e., 1-4 MeV, 4-8 MeV, 8-16 MeV, and 16-215 MeV. The dotted red line corresponds to the threshold of 10 protons/(cm^2-s-sr).

Diff Flux-GWC: Differential proton flux as a function of time for the energy ranges 0.8-1.2 MeV, 4-6 MeV, 9-11 MeV, 14-16 MeV, and 49-51 MeV. The dotted red line corresponds to a threshold of 10 protons/(cm^2-s-sr).

Integ Flux: Integral proton flux as a function of time at geosynchronous altitude for energy ranges measured by the Space Environment Monitor on the GOES satellites, i.e., at greater than 10, 30, 50, 100, and 500 MeV, respectively. The dotted red line corresponds to a threshold of 10 protons/(cm^2-s-sr).

The following output options are also selectable from the PPS Environment window,

Plot Options: This widget allows one to set the Y-axis min, max and number of tics for the plots. The *Auto* button gives (rounded) limits spanning the data and the default is set at -5 to 5 (log10).

Display Text: Clicking the *Display Text* button displays the text window if it was closed.

The SAAMAPS-2007 Science Module (Static Only)

Model Name: SAAMAPS-2007

Version: July 2007

Developer: Air Force Research Laboratory and Boston College

Reference: Ginet, G. P., Madden, D., Dichter, B.K., and Brautigam, D.H., Energetic proton maps for the South Atlantic anomaly, *AFRL-RV-HA-TR-2008-1060*, Air Force Research Laboratory, Hanscom AFB MA (2008), ADA 485155 [see $AFGS_HOME\models\REFS\SAAMAPS_2007.pdf]

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

SAAMAPS-2007 Overview

For low-Earth orbit (LEO) satellites, anomalies related to single event effects (SEEs) can result from interaction with the high-energy radiation belt protons. The dominant source of proton fluence (outside of solar proton events) is the South Atlantic Anomaly (SAA), a localized region at fixed altitude with high flux intensities resulting from the asymmetry in the Earth's magnetic field. As summarized by *Ginet et al.* (2008), previously, the location of the SAA was often determined by using the proton intensity maps derived from the NASA AP radiation belt climatology models (see *The NASAPRO Science Module* chapter of this document for details). However, with the SAA drifting westward approximately 0.3 degrees/year updates are needed. Subsequently, an improved set of single event effects maps was developed from data taken by the Air Force APEX and CRRES satellites for epoch 1990-1996 (see The *SEEMAPS-1998 Science Module* chapter of this document). Most recently, the South Atlantic Anomaly Maps (SAAMAPS) represented in this science module were developed by *Ginet et al.* (2008) who confirmed the continued westward drift of the SAA. SAAMAPS-2007 provides access to a geographically tagged database of energetic proton flux intensities for the epoch 2000-2006 based on data from the Compact Environment Anomaly Sensor (CEASE) flown onboard the Tri-Service Experiment-5 (TSX-5) satellite in a 410 km x 1710 km, 69° inclination orbit.

SAAMAPS-2007 Inputs

The SAAMAPS Science Module requires the user to specify the following information to determine which data set to use in mapping the data,

Altitude: This parameter determines which of the proton flux data sets representing 26 altitude bins (400 and 1,650 km) is to be considered. The altitude range of each value extends 50 km above the listed value. Select *All* at the top of the list to load all altitudes or select a single altitude (km) from the list.

SAAMAPS-2007 Outputs

The SAAMAPS Science Module returns a 3D Gridded Data Set of proton flux (#/cm^2-sec-str) for 5 integral energy channels (>23, >38, >66, and >94 MeV) for the selected altitude bin (or all bins). The output map resolution is fixed (3° latitude x 3° longitude x 50 km).

The SEEMAPS-1998 Science Module (Static Only)

Model Name:	SEEMAPS-1998
Version:	September 1998
Developer:	Radex, Inc. (now AER, Inc.)
Reference:	Gussenhoven, M.S., E.G. Mullen, D.A. Hardy, D. Madden, E. Holeman, D. Delorey, and F. Hanser, Low Altitude Edge of the Inner Radiation Belt: Dose Models from the APEX Satellite, *IEEE Trans. Nucl. Sci., 43*, 2035-2042 (1995)
	Mullen, E.G., G. Ginet, M.S. Gussenhoven, and D. Madden, SEE Relative Probability Maps for Space Operations, *IEEE Trans. Nuc. Sci., 45*, 2954-2963 (1998)
	Sawyer, D.M. and J.I. Vette, AP-8 Trapped Proton Environment for Solar Maximum and Solar Minimum, *NSSDC WDC-AR&S 76-06, NASA-GSFC TMX-72605*, Greenbelt, MD (1976)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

SEEMAPS Overview

The Single Event Effects Maps (SEEMAPs) are a geographically tagged database of the relative probability for satellite on-board micro-electronics to suffer single event effects in the low Earth orbit (LEO) regime. Until now, the most readily accessible and usable means to determine the SEE risk, either for design or operations, was by using proton contours from the NASA Particle Maps [*Sawyer and Vette*, 1976]. However, both data and our physical understanding of the Earth's magnetic field movement indicate that the location of the energetic proton belts has changed significantly since these maps were made in 1970.

The SEEMAPs are an improved model for determining relative risk assessment from SEEs in the near-Earth space in the present epoch based on data taken from the Advanced Photovoltaic and Electronics (APEX) and Combined Radiation and Release Experiment (CRRES) satellites. The data cover the period from July 1990 to October 1991 (CRRES, near solar maximum) and from August 1994 to May 1996 (APEX, near solar minimum). A comparison of radiation dose from the two spacecraft as well as from the Defense Meteorological Satellite Program (DMSP) F7 spacecraft for the previous solar minimum period (1984-1987) is given by *Gussenhoven et al.* [1995]. This work showed that there was a small variation in proton dose over the last solar cycle. The fact that the change was small for inner belt protons gives us reason to believe that the combined APEX and CRRES databases give a near worst-case model (solar minimum) useful for orbit trade-off studies and mission operations planning.

An excerpt from *Mullen et al.* [1998] describes the basic SEEMAP construction and capability:

> "Normalized flux and dose data for protons with energies >50 MeV are used to produce contour maps of relative probabilities of experiencing SEEs in the Earth's inner radiation belt. The data were taken on the APEX and CRRES satellites. To make the maps, the data are averaged in 3^{o} x 3^{o} bins in geographic latitude and longitude, and in 50 km steps

> in altitude. All geographic longitudes and latitudes less than or equal to 70° are covered. The altitude range extends from 350 km to 14,000 km. This geographic range includes the complete region of inner belt > 50 MeV protons, except in the South Atlantic Anomaly region below 350 km. The maps easily locate regions of high risk for SEEs and are designed primarily for use in space mission planning and operations. The data base includes the added proton peak following the March 1991 magnetic storm, but does not include SEE probabilities in the polar cap region associated with high energy solar particle events."

Though the SEE relative probability maps are constructed from data sets of flux rates corresponding to > 50 MeV particles depositing energy in the APEX and CRRES dosimeters, these flux rates were carefully compared with both the >50 MeV dose rate and single event upsets measured in a solid state tape recorder on-board APEX. The correlation was found to be good. Relative probabilities were computed by dividing the dosimeter flux rate by a normalization factor of 2360.45, which gives relative probability values in the range of 0 to 5.5. This factor was based on APEX measurements as explained in *Mullen et al.* [1998]:

> "... a normalization factor is calculated from the average flux rate for the HILET A Dome 4 [dosimeter] between the altitudes of 1,000 and 1,050 km for data points between 1,000 and 5,000 counts/s. This altitude and count rate level were chosen because they are near the middle of the altitude range, have sufficient points for good statistics, are the highest count rates for the altitude range, and are most easily remembered (>1000 counts/s at 1000 km)."

The SEEMAPS should be most useful for a space system operator to a) tell when and how the spacecraft enters regions of high intensity (like the SAA) and the time spent in the region, b) estimate how many upsets to expect in every region by keeping track of when and where upsets occur and then using the normalization factors, and c) determine the factor to go from normalized values to upsets/device/unit time/region once the upset data base is large enough.

SEEMAPS Inputs

The SEEMAPS Science Module requires the user to specify the following information to determine which data set to use in mapping the data,

Altitude Bins:	The altitude bins parameter determines which of the proton flux data sets corresponding to bins between 350 and 15,000 km is to be considered. Select the *All* to load all altitude or select *One* to load a single altitude and highlight one of altitude ranges in the *Bin Ranges (Km)* list.
Activity:	The activity parameter specifies whether the *Quiet* (obtained before the 24 March 1991 storm) or *Active* (obtained after the 24 March 1991 storm) proton flux data sets are to be used. This parameter is the same as that used in the CRRESPRO module (see the CRRESPRO Science Module).

SEEMAPS Outputs

The SEEMAPS Science Module returns a 3D Gridded Data Set of the proton flux (#/sec) and relative probability value (*RELATIVE PROB*) for the selected altitude bin (or all bins) and activity level.

The STOA Science Module (V2.5.1 and Static Only)

Model Name:	Shock Time of Arrival (STOA)
Version:	1.0 (1987)
Developer:	D. Smart, Air Force Research Laboratory; M. Dryer and L.D. Lewis, NOAA Space Environment Center
References:	Fry, C.D., M. Dryer, Z. Smith, W. Sun, C.S. Deehr, and S.-I. Akasofu, Forecasting solar wind structures and shock arrival times using an ensemble of models, *J. Geophys. Res.*, *108*(A2), 1070, doi:10.1029/2002JA009474(2003)
	Hilmer, R.V., G.P. Ginet, K. Kadinsky-Cade, S. Quigley, D.T. Decker, P.H. Doherty, Space Environment Models Addressing Operational Hazards: An AF-GEOSpace Perspective on Current Capabilities, *American Institute of Aeronautics and Astronautics, AIAA 2000-0366*, from *38th Aerospace Sciences Meeting*, 10-13 January 2000, Reno NV, 2000.
	Smart, D.F., M.A. Shea, M. Dryer, A. Quintana, L.C. Gentile and A.A. Bathurst, Estimating the Arrival Time of Solar - Flare - Initiated Shocks by Considering them to be Blast Waves Riding over the Solar Wind, in Simon, P.A., G. Heckman and M.A. Shea, Eds., *Solar-Terrestrial Predictions: Proceedings of a Workshop at Meudon*, France, June 18-22, 1984, U.S. Government Printing Office, Washington, D.C., pp. 471-481 (1986)
	Smart, D.F. and M.A. Shea, A Simplified Model for Timing the Arrival of Solar Flare-Initiated Shocks, *J. Geophys. Res., 90,* 183-190 (1985)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

STOA Overview

The sudden release of energy into the solar atmosphere will create a shock wave. The STOA model applies the Sedov similarity theory to the general characteristics of the interplanetary medium [*Sedov*, *Similarity and Dimensional Methods in Mechanics*, Academic Press, New York, 1959]. The STOA concept is a blast wave propagating over the pre-existing solar wind. When an interplanetary shock has been generated by a solar disturbance, the STOA science module can be invoked to predict the arrival time of the shock at the Earth or at another ecliptic plane location. We refer to the shock-producing solar events, whether they are coronal mass ejections or solar flares, as "solar flares," because the model was originally developed assuming that solar flares were the drivers for the interplanetary shocks.

The STOA shock speed profile as a function of radial distance has been found to compare favorably with 2 1/2-D MHD simulations of interplanetary shocks propagating along the flare-radial direction, for test cases where the initial shock speeds were identical (see review by *Wu*

[*Space Science Reviews, 32*, 115, 1982]). The MHD models simulate the behavior of solar flare initiated shock waves propagating through interplanetary space.

The STOA arrival time is calculated by modeling the shock propagation in two phases: a "driven" phase and a "blast" phase. During the initial driven phase the shock is assumed to be driven by the solar flare. It is assumed that the shock disturbance originates in the solar atmosphere at a distance R=0.007 AU from the center of the Sun. A constant speed is assigned to this driven phase and is assumed to be given by the frequency drift rate of the Type II radio burst with the onset time coinciding with the beginning of the burst. The end time of the driven phase is the time when the soft X-ray emission power has decayed to half of the log of the maximum flux above the pre-event background. The radial distance covered by the driven phase is given by the product of the Type II drift speed multiplied by the driver time.

The distance from the Sun's center to the end point of the driven phase in a flare radial direction is

$$R_d = 0.007 + V_d\, T_d \quad \text{(AU)}.$$

The initial condition simulated by STOA is a shock front that may extend across a major part of the Sun, with a shock front speed profile given by

$$V_\theta = V_r\, f \quad \text{with} \quad f = (\cos(\theta)+1)/2$$

where θ is the angle measured at the center of the Sun between the flare radial direction and any other radial direction. The driven distance at an angle θ is

$$R_{d\theta} = 0.007 + f\, V_d\, T_d \text{ (AU)}.$$

After the driven phase it is assumed that the propagation of the disturbance through the interplanetary medium can be described as a blast wave superimposed on the preexisting solar wind. Only the shock front or leading edge of the blast wave is considered in this model; no information is provided on the structure of the shock wave. The average radial blast wave speed is obtained by integrating the blast wave equation in the flare radial direction.

In the interplanetary medium it is assumed that the density is proportional to the inverse square of the distance R from the center of the Sun, and that the blast wave speed decreases as $R^{-1/2}$. The average radial blast wave speed is projected onto the Sun-observer direction using the foreshortening factor described earlier. It is assumed that the speed anisotropy adopted for the driven phase persists through the blast phase. Finally, the average speed of the disturbance during the blast phase is the average blast wave speed in the observer direction added vectorially to the average solar wind speed. For simplicity, it is assumed that the solar wind is moving radially away from the Sun at a constant speed. In a flare radial direction, the wave speed is

$$V = B\, R^{-1/2} + V_{sw} \qquad \text{with constant } B = V_d\, R_d^{1/2}.$$

In a non flare-radial direction the shape factor is involved and the wave speed is

$$V_\theta = f\, B\, R^{-1/2} + V_{sw} \qquad \text{with } V_\theta = dR/dt,$$

that is integrated from $R = R_{d\theta}$ to obtain the shock's propagation time to the desired radius R.

The predicted shock arrival time is simply the sum of the initial Type II burst time, the driven phase duration and the travel time of the disturbance through the interplanetary medium. As the

blast wave loses energy during its propagation through the interplanetary medium, the shock speed decays to the magneto-acoustic speed. The program computes the sonic Mach number and Alfven speed in interplanetary space, using simple approximations for interplanetary plasma density, temperature and magnetic field as a function of distance from the Sun, and derives the magneto-acoustic Mach number of the shock. If this number is less than Mach 1 at the Earth or other selected observation point, no shock is predicted to arrive.

The STOA documentation and associated references suggest that shocks that are capable of propagating to 1 AU are likely to be associated with “big flares”. The criteria for identifying a big flare are not, however, clearly established. There is an indication, based on the original testing of the program, that the better STOA predictions are associated with “long duration soft X-ray events”. This means a decay time T_d of one hour or more, together with a velocity Vd equal or greater than 1000 km/s. Other diagnostics of shock generation and propagation into the solar corona may be coronal mass ejection information and forecaster judgment.

STOA Inputs

The STOA science module requires the following inputs:

Global Parameters: Year, Day, UT (used to initialize event onset and end times)

Specify Event Duration: The user can choose to specify either the *Stop Time* of the event, the *Duration* of the event, or have the event duration estimated from inputs of the associated GOES soft *X-ray Levels*.

Observer Location: The observer location can be designated as *Earth* or the user can *Specify* a location. The latter choice prompts the user to enter the observer distance (*Obs. Distance*), offset angle (*Obs. Offset Angle*), and name (*Obs. Name*) in the lowest three text boxes on the right side of the window as described below.

Event onset time: Time of onset of Type II radio burst from USAF RSTN site in the format MM/DD/YY HH:MM. Default is the start time from the top of the environment window.

Event end time: When *Stop Time* is selected to specify the event duration, the user enters the event end time in the format MM/DD/YY HH:MM. The end time of the shock driver must not be earlier than the Type II event onset time. The shock driver time must be less than 7 days (168 hours). Shock driver durations are typically a fraction of a day. In this case, GOES satellite X-ray levels are not used to estimate the event duration.

Event duration: When *Duration* is selected to specify event duration the user enters the event duration in hours. The shock driver time must be < 7 days (168 hours). Shock driver durations are typically a fraction of a day. In this case, GOES satellite X-ray levels are not used to estimate the event duration.

Backg. Class: When *X-ray Levels* is selected to specify the event duration, the user enters the background X-ray level measured by the 1-8 Angstrom X-ray instrument on a GOES satellite before the event occurred. This value is

entered with a classification letter and a numeric field. The usual X-ray event classification letters A, B, C, M, or X can be used with the numeric field consisting of 1-3 characters which may be digits or an optional decimal point. The numeric field multiplies the flux level. The range of allowed values is A1 through X99.

Peak Class: When *X-ray Levels* is selected to specify the event duration, the user inputs here the peak X-ray level measured by the 1-8 Angstrom X-ray instrument on a GOES satellite during the X-ray event. The format is the standard X-ray event classification scheme as explained above. After entering this value the user should click a different *Specify Event Duration* option and then the *X-ray Levels* choice again so that the level XN.N corresponding to 1/2 log of the peak signal will be displayed next to *Decay time* box.

Decay time, level XN.N: When *X-ray Levels* is selected to specify the event duration the user enters the time in the format MM/DD/YY HH:MM at which the X-ray level measured by the 1-8 Angstrom X-ray instrument on a GOES satellite during the X-ray event decays to the level XN.N. The *level XN.N* is calculated from the *Backg. Class.* and *Peak. Class*. Of course, this time will occur after the peak of the X-ray event.

Type II Speed(km/s): The Type II drift speed in km/s calculated by the USAF RSTN network and select other radio telescope sites from observations of Type II radio bursts. This value must be greater than 0 and less than 10000 km/s.

Flare lat (deg N): The solar latitude, between +90° and -90° North, of the solar flare associated with the Type II radio burst. This information can be obtained from H-alpha observations by the USAF SOON or other optical sites or from X-ray images. Degrees South are entered as negative numbers.

Flare lon (deg W): The solar longitude, between +180° and -180° West, of the solar flare associated with the Type II radio burst. This information can be obtained from H-alpha observations by the USAF SOON or other optical sites or from X-ray images. Degrees East are entered as negative numbers. Longitudes greater than +/- 90° from the direction of the observer may not be realistic.

Solar Wind (km/s): The solar wind speed must be positive and less than 1000 km/s.

Obs. Distance: When the user wishes to *Specify* the *Observer Location* they enter the observer distance in AU. It must be greater than 0.007 AU and less than 100 AU. Note that observer distances less than 0.2 AU or greater than 50 AU are unrealistic. This condition is not detected until all of the data have been entered because it depends on several data entries.

Obs. Offset Angle: When the user wishes to *Specify* the *Observer Location* they enter the observer offset angle in degrees. It is the offset angle from the Sun-Earth line, from -360° to +360°, and is measured in the ecliptic plane, in the same sense as the longitude of the solar flare: west is positive, east is negative.

Obs. Name:	When the user wishes to *Specify* the *Observer Location* they enter the observer name as a 5 character alphanumeric value. If this field is left blank STOA uses the Earth as the default observer.
Display Text:	Click the *Display Text* button to display the text window if it was closed.

STOA Outputs

STOA returns a text message window containing the results of the model calculations and a summary of the input parameters. The model outputs are:

- Magneto-acoustic Mach number and arrival time of shock at observation point
- Total propagation time of shock in hours and minutes
- Type II onset time
- X-ray or other event end time
- Driver duration time in hours
- Type II speed in km/s
- Solar flare latitude and longitude
- Solar wind speed
- Distance from Sun to observer (e.g., Earth) in AU

The TPM-1 Science Module (V2.5.1 Only)

Model Name:	Trapped Proton Model (TPM-1)
Version:	Version 1.2, 15 April 2003; IGRF updates 2009
Developer:	S. L. Huston, The Boeing Company; IGRF option updates by AER, Inc.
References:	Huston, S.L., Space Environment and Effects: Trapped Proton Model, *NASA/CR-2002-211784*, NASA Marshall Spaceflight Center (2002) [see $AFGS_HOME\models\REFS\TPM.pdf]
	Huston, S.L., and K.A. Pfitzer, Space Environment Effects: Low Altitude Trapped Proton Model, *NASA/CR-1998-208593*, NASA Marshall Spaceflight Center (1998)
	Huston, S.L, G.A. Kuck, and K.A. Pfitzer, Low altitude trapped radiation model using TIROS/NOAA data, in *Radiation Belts: Models and Standards*, J.F. Lemaire, D. Heynderickx, and D.N. Baker (eds.), *Geophysical Monograph 97*, American Geophysical Union, 119 (1996)
	Meffert, J.D., and M.S. Gussenhoven, CRRESPRO Documentation, *PL-TR-94-2218*, Phillips Laboratory, Hanscom AFB, MA (1994), ADA 284578
	Olson, W.P., and K.A. Pfitzer, Magnetospheric Magnetic Field Modeling, Annual Scientific Report, Air Force Office of Scientific Research contract F44620-75-C-0033, McDonnell Douglas Astronautics Co., Huntington Beach, CA (1977), ADA 037492

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

TPM-1 Overview

The TPM-1 science and application modules are based on the Trapped Proton Model (TPM) developed by Boeing Corporation for the NASA Space Environment and Effects (SEE) Program [*Huston,* 2002]. TPM combines both the Low Altitude Trapped Radiation Model (LATRM) [*Huston et al.,* 1998], also developed by Boeing for NASA/SEE, and the Air Force Research Laboratory's (AFRL) CRRESPRO model [*Meffert and Gussenhoven,* 1994] covering higher altitudes. From the introduction of the TPM-1 report [*Huston,* 2002]:

> "This new model [TPM-1] combines elements of LATRM and CRRESPRO to obtain a model which covers the full spatial extent of the trapped proton belts, determines the differential proton flux over the range of 1 to 100 MeV, and contains a solar cycle variation at low altitudes."

A description of the CRRESPRO model can be found in the CRRESPRO Science Module section of this manual. The LATRM model (also known as the NOAAPRO model) is described in the LATRM report [*Huston and Pfitzer,* 1998] as follows:

> "Under NASA's Space Environment Effects (SEE) program, the Boeing Company has developed a new model for the low-altitude trapped proton environment. The model is

based on nearly 20 years of data from the [Medium Energy Proton and Electron Detector (MEPED), a component of the Space Environment Monitor (SEM) package onboard the] TIROS/NOAA weather satellites [orbiting at 840 km and 93 degrees inclination].

The model, which we have designated NOAAPRO (for NOAA protons), predicts the integral omni-directional proton flux in three energy ranges: >16, >36, and >80 MeV. It contains a true solar cycle variation and accounts for the secular variation in the Earth's magnetic field. It also extends to lower values of the magnetic L parameter than does AP8. Thus, the model addresses [some of the] major shortcomings of AP8 ...

For each energy channel, the model data are organized in terms of L and B/B_{min} (although these parameters are mapped into coordinates more appropriate to the data space). The model consists of parameters which determine the absolute magnitude of the proton flux, the variation of the proton flux with the solar 10.7 cm radio flux ($F_{10.7}$), and the phase lag between $F_{10.7}$ and the proton flux. This approach results in a well-organized data set for two solar cycles, and can be extended into the future."

The features of TPM-1 are further summarized in the conclusions of the TPM-1 report:

"The development of TPM-1 represents a significant advance in the field of trapped proton modeling. It is now possible to predict the trapped proton flux in the energy range 1-100 MeV with good accuracy over several solar cycles. TPM-1:

- Covers the geographic region from approximately 300 km to geosynchronous orbit.
- Calculates omni-directional differential flux in 22 energy channels ranging from 1.5 to 81.5 MeV.
- Contains a continuous variation with solar activity, valid over the time span 1960-2020. The solar cycle variation is driven by the solar 10.7 cm radio flux ($F_{10.7}$).
- Contains a model for both quiet (nominal) and active conditions, e.g., after an event such as the one observed by CRRES [in which a new belt was produced by the March 1991 interplanetary shock event].
- Can be used to obtain the flux at a particular point in space [TPM-1 Science Module], or combined with an orbital integration to obtain orbit-averaged energy spectra [TPM-1 Applications Module].

At low altitudes, TPM-1 tends to predict harder energy spectra than does the previous AP-8 model [see NASAPRO Science Module section of this manual]. The TPM-1 flux at energies above about 10 MeV is higher than the AP-8 predictions, while the reverse is true below 10 MeV. At higher altitudes, the shapes of the TPM-1 and AP-8 spectra are similar. Orbital integrations show that the proton flux varies over the solar cycle by a factor of two at higher energies, with the variation decreasing as the energy decreases."

The TPM-1 Science Module is used to map the proton flux data sets used by TPM-1, stored in modified magnetic coordinates [see TPM-1 report], onto a three-dimensional spatial grid specified by the user. The mapping is accomplished using either the original TPM-1 algorithms (which uses the IGRFXX model, where XX is the year, mod 5, closest to but earlier then the data

being requested) or the AFRL algorithms which give a choice of simpler magnetic field models, e.g. a tilted/offset dipole.

After selecting a proton energy and magnetic field model, the module calculates the modified magnetic coordinates for each user-specified spatial grid point. Resulting flux values are then obtained from interpolating between the TPM-specified modified magnetic grid point values in the TPM data files. In this manner, a fully three-dimensional map of the proton flux data may be obtained.

Note: Although AF-GEOSpace allows the data to be mapped in three dimensions using a variety of magnetic field models, the TPM-1 option is most consistent with the reduction of the original data.

TPM-1 Inputs

The TPM-1 Science Module requires the user to specify the following information to determine which data set to use and which magnetic field model to use in mapping the data,

Energy Channel (MeV): The energy channel parameter selects which of the proton flux data sets corresponding to the twenty-two energy channels between 1 and 100 MeV used in CRRESPRO is to be used [see CRRESPRO Science Module section for detailed energy channel descriptions].

Mode: Determines whether the original TPM-1 mapping or AFRL mapping is used to go between spatial and magnetic coordinates.

TPM-1: Uses TPM-1 mapping

AFRL: Uses AFRL mapping. If selected, then the user must pick the magnetic field model to be used. Originally and as presented in AF-GEOSpace Version 2.1, magnetic field models *IGRF85* and *IGRF85/O-P* were offered. However, after including time-dependent IGRF internal field capabilities covering 1945-2010, the current *B-Model* options include.

B-Model: Dipole: A dipole field

Dipole-Tilt: A tilted dipole field

Dip-Tilt-Off: A tilted-offset dipole field

IGRF: The International Geomagnetic Reference Field with no external contributions (Extrapolation beyond 2010).

IGRF/O-P: The *IGRF* internal field with the *Olson and Pfitzer* (1977) static model to represent the external field.

Activity: The activity parameter specifies whether the *Quiet* (obtained before the 24 March 1991 storm) or *Active* (obtained after the 24 March 1991 storm) proton flux data sets are to be used.

F10.7 Plot: Produces a plot of the F10.7 data associated with the *File* option of the *F10.7* source selection (see next item).

F10.7 Data: Specifies the F10.7 data source used for calculation of the TPM-1 solar cycle variation.

TPM-1 File:	Use the file supplied with the original distribution which contains projections of F10.7 out to 2020.
Globals:	Use the global parameter set within AF-GEOSpace. Note that if *Globals* is selected then the time of execution must by less than or equal to the time of the latest update of the Global parameter set.

TPM-1 Outputs

The TPM-1 Science Module returns a 3D Gridded Data Set of the omni-directional proton flux for the selected energy channel and activity level in units of #/(cm^2 s MeV).

The WBMOD Science Module (V2.5.1 Only)

Model Name:	Wide-Band Model (WBMOD)
Version:	15.03 (08 July 2005)
Developer:	Northwest Research Associates, Defense Nuclear Agency, and Air Force Research Laboratory
References:	Cervera, M.A., R.M.Thomas, K.M. Groves, A.G. Ramli, and Effendy, Validation of WBMOD in the Southeast Asian region, *Radio Science, 36*, 1559-1572 (2001)
	Secan, J.A., and R.M. Bussey, An Improved Model of High-Latitude F-Region Scintillation (WBMOD Version 13), *PL-TR-94-2254* (1994), ADA 288558
	Secan, J.A., R.M. Bussey, E.J. Fremouw, and Sa. Basu, An Improved Model of Equatorial Scintillation, *Radio Sci., 30*, 607-617 (1995)

Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

WBMOD Overview

WBMOD is a climatological model for ionospheric scintillation. Because WBMOD is a climatological model, it is best suited for long-range planning and engineering studies. It is not as well suited for daily planning or operations. WBMOD specifies S4, 95th percentile fades, and other scintillation parameters for trans-ionospheric radio-wave propagation paths given: a location on the globe, a satellite above 100 km altitude, an RF frequency above 100 MHz, and several geophysical activity indices. Please note that the previous release, AF-GEOSpace V2.1, contained WBMOD Version 14.02 (31 December 2000).

WBMOD Inputs

The WBMOD science module requires the following inputs,

Global Parameters: Day, UT, Kp, and SSN (note: Year, F10.7 and Ap are not used).

Propagation: Specifies whether *1-Way* or *2-Way* propagation effects should be calculated. For the *2-Way* option, the user must also input the following,

- Up/Dn Link Corr: The correlation between up-link and down-link signals. For up/down links between the same transmitter and receiver, this parameter should be set to 1; for bi-static links with spatially separated receivers set it to 0.

In-situ Vd: F region plasma drifts; calculated by WBMOD using models when the *Model* option is selected or specified explicitly by the user when the *Input* option is selected. When the *Input* option is selected the user must specify the following,

- Vd, North (m/s): Northward F region plasma drift in meters/second.

Vd, East (m/s): Eastward F region plasma drift in meters/second.

Vd, Down (m/s): Downward F region plasma drift in meters/second.

Step: Option to step (move) the receiver (*Rcvr*) or the transmitter (*Tran*). Normally the transmitter is a satellite and the receiver is ground-based. Moving the receiver or satellite maps out regions of scintillation. We recommend that the user use the step receiver mode *Rcvr*. This mode will produce a map that is easiest to interpret.

Note: In the step transmitter mode, *Tran*, data are for scintillation on the ray-path from the satellite to the receiver and plotted at the sub-satellite point. This display location is not the ionospheric location where the scintillation occurred. Similarly, for the step receiver mode, *Rcvr*, the data will be plotted at the receiver location, not the ionospheric location where scintillation occurred.

EP Boundary: The location of the equatorward boundary of auroral precipitation may be calculated by WBMOD in the following ways,

Eff. Kp: An effective Kp calculated explicitly from a DMSP observation of the equatorward boundary in magnetic latitude and local time is used. If selected, the following must be specified,

Effective Kp: The effective Kp derived from the equatorward boundary location observed by a DMSP SSJ/4 sensor (different from the Global Parameter Kp).

Explicit: EP boundary locations are specified directly by the user. If selected, the following must be specified,

EP Bndry MLAT: The magnetic latitude of an equatorward boundary crossing observed by the SSJ/4 sensor on DMSP.

EP Bndry LT: The local time of an equatorward boundary crossing observed by the SSJ/4 sensor on DMSP. This must be consistent with the *EP Bndry MLAT* entered above.

Use Kp: Kp from the Global Parameters is used.

Output: WBMOD output can be determined by two different calculation methods,

Percentile: WBMOD computes the S4 scintillation index and other parameters for user defined climatological percentile, i.e., level of disturbance. If selected, the following must be specified,

Percentile(0.0-1.0): This percentile selects the level of disturbance, i.e., the S4 that corresponds to this percentile. Typical procedures use 90th percentile (the 10th worst disturbance level).

	Threshold: WBMOD computes the percentage of time that either the S4 or phase index exceeds a certain threshold value. If selected, the following must be specified, Thresh. Param: Either the *S4* or *Phase* index can be selected for threshold parameterization (toggle). Threshold: The threshold level is dimensionless for *S4*, ranging from 0.0 to 1.2, and is in radians for *Phase*.
Trans. Freq (MHz):	Specifies transmitter frequency for scintillation calculation in MHz.
Trans.Alt (km):	Specifies altitude of transmitter (satellite) in km.
Fixed End Lat:	Geographic latitude in degrees of transmitter or receiver, depending on which is fixed as specified by *Step* option.
Fixed End Lon:	Geographic longitude in degrees of transmitter or receiver, depending on which is fixed as specified by *Step* option.
Phase Stability (s):	Length of time in seconds over which phase stability is required for operational system. For communication applications this parameter approaches zero and is not critical. For applications involving coherent data integration (e.g., radar) this parameter should be set equal to the integration period.
Kp@Local Sunset:	The value of Kp at the time of last sunset at the ground-based transmitter or receiver location. If a value of -1 is used, the program defaults to the value of Kp used in the EP Boundary computation.

WBMOD Outputs

The WBMOD science module returns 2D Gridded Data Sets. We recommend displaying output in 2D plots using the COORD-SLICE graphical object. AF-GEOSpace will then display a spatial distribution (map) for the following parameters:

95%tile FADE:	The 95th percentile fade depth of the signal intensity (decibels). Don’t confuse this percentile with the climatological percentile input to WBMOD. For example, if the user selected a 90th percentile climatology, then this output represents the 5th most severe fade on the 10th most disturbed day. Fades are plotted as positive values.
S4:	The S4 scintillation index, a normalized standard deviation of the signal intensity (dimensionless).
STDDEV PHASE:	The standard deviation of the phase (radians), also known as sigma-phi.
STDDEV LOG(I):	The standard deviation of the log of the intensity (decibels).
%Time:	The percentage of time that *S4* or *Phase* exceeds a specified threshold level for given conditions (%). This parameter is meaningful only when the model has been run in *Threshold* mode.

APPLICATION MODULES

Application modules provide orbit creation/prediction, dataset integration along orbits, magnetic field model generation, and access to specialized ionospheric ray-tracing, graphics, and scintillation products. The application modules are accessed through the application manager that becomes visible when the *Application* option in the *Module* pulldown menu is activated. The application manager consists of two lists - *Available Modules* and *Active Modules*. *Available Modules* are the modules that are currently supported by AF-GEOSpace. *Active Modules* are modules that have been created and used by the AF-GEOSpace user during the current session.

When initially accessed, the application manager will show a list of applications under *Available Modules*. Since no applications have yet been created, the *Active Modules* list will be empty.

Currently, the following applications are supported by AF-GEOSpace:

- **APEXRAD-APP:** Advanced Photovoltaic and Electronics Experiments (APEX) radiation dose model calculates expected accumulated yearly dose (in units of rads silicon/year) for four thicknesses of aluminum shielding during four levels of magnetic activity. Best for orbits with apogees less than 2500 km (see the CRRESRAD-APP for higher altitudes).
- **BFIELD-APP:** The B-Field application allows the generation of datasets representing the magnetic field in the near-Earth space environment. A variety of internal (dipole, IGRF) and external [*Olson and Pfitzer* 1977; *Hilmer and Voigt* 1995; *Tsyganenko* 1987; *Tsyganenko* 1989; *Tsyganenko* 2002; *Tsyganenko and Sitnov* 2005] field models are used to generate gridded data set, field lines, and flux tubes.
- **BFOOTPRINT-APP:** Traces geomagnetic field-lines from single user-specified points (defined in either geographic or magnetic coordinates) or multiple points along a satellite orbital track. The resulting field-lines, orbital track, and list of footprint locations on the Earth's surface can be viewed.
- **CRRESELE-APP:** Combined Radiation and Release Effects Satellite (CRRES) electron flux model specifies the location and intensity of electron omnidirectional fluence (integral and differential) over the energy range 0.5-6.6 MeV for a range of geomagnetic activity levels. A user-specified orbit is traced through the electron flux models to provide an estimate of electron fluence received by the satellite under a wide range of magnetospheric conditions.
- **CRRESPRO-APP:** Combined Radiation and Release Effects Satellite (CRRES) proton flux model calculates proton omnidirectional fluence (integral and differential) over the range 1 to 100 MeV for user specified orbits and quiet, active, or average geophysical activity levels.
- **CRRESRAD-APP:** Combined Radiation and Release Effects Satellite (CRRES) space radiation dose model calculates expected satellite dose accumulation behind four different thicknesses of aluminum shielding for user-specified orbits for active or quiet geophysical activity levels.
- **IONSCINT-G-APP:** This application combines the GPS scintillation scenario tools of the IONSCINT-G Science Module with the orbital ephemerides of individual spacecraft to provide a time-series of S4 scintillation index values for each platform-spacecraft link.

- **LET-APP:** Calculates the linear energy transfer (LET) spectrum and its associated single event upset (SEU) rate in a microelectronic device resulting from the penetration of energetic space particles. Effects from both cosmic rays and the trapped protons are estimated by using the CHIME and CRRESPRO models as inputs.
- **METEOR IMPACT-APP:** Calculates meteor flux or damage rates for given cross section, pit depth, and material type as a function of time along a user-specified orbit. Cumulative probabilities for flux and damage rates are also determined. The module accounts for meteor flux variations at the satellite owing to both position changes and meteor shower and storm temporal variations.
- **NASAELE-APP:** Calculates electron omni-directional fluence (differential and integral) for ten energy intervals in the range 0.65-5.75 MeV. A user-specified orbit is traced through NASA AE-8 trapped electron model to provide an estimate of electron fluence received by the satellite under a wide range of magnetospheric conditions.
- **NASAPRO-APP:** Calculates proton omni-directional fluence (differential and integral) over the energy range 1.5-81.3 MeV for user specified orbits and quiet or active geophysical conditions using the NASA AP-8 trapped proton model.
- **RAYTRACE-APP:** Calculates the behavior of MHz rays in an ionosphere specified by a Parameterized Ionosphere Model (PIM) data set.
- **SATEL-APP:** Calculates orbital trajectories for satellites from a variety of user specified orbital element input sets. Also calculates properties of associated satellite detector cones and ground-to-satellite links
- **TPM-APP:** Following the procedures established for CRRESPRO-APP, this application instead uses the TPM-1 proton flux maps to calculate proton omni-directional fluence (integral and differential) over the range 1 to 100 MeV for user specified orbits during periods with quiet, active, or average geophysical activity levels.
- **WBPROD-APP:** Gives a 24hr WBMOD climatology prediction of the dB fade levels due to ionospheric scintillation effects for specific ground-to-satellite communication links.

Running Application Modules

To run an application module, use the mouse to select the *Applications* option in the *Module* pulldown menu and *Available Modules* and *Active Modules* lists will appear in the Environment Window. Click on the desired choice under *Available Modules*. For example, to create a new version of CRRESELE-APP, click the mouse on *CRRESELE-APP* in the *Available Modules* list. Choosing an applications module will do two things: first, the choice is added to the *Active Modules* list; second, the options associated with the chosen application module will appear in the Environment Window. In general, each application module will have a different Environment Window representing the module specific inputs. Adjust the module inputs as required. Before actually running the module, the following two adjustments might be considered which can effect run time and the size of the output files.

First, the *Grid Tool* option in the *Edit* pulldown menu can be used to modify the grid to be filled with data using the selected application module.

Second, the *Dynamic Tool* option in the *Edit* pulldown menu can be used to adjust both the time step to be used and the specific output parameters to be calculated if a *Start* and *End* time have been set at the top of the window, i.e., the run is dynamic. For static runs only a *Start* time is specified and all output parameters are calculated by default.

Finally, the *Run/Update* option in the *Edit* pulldown menu is used to run or re-run the module after any settings have been changed. When the module run is complete a message stating that the MODEL IS READY AND UP TO DATE will appear in the *Model Status* box at the bottom of the Environment Window. At this point, the data produced are ready for display using graphical modules.
Also, the *Delete* option in the *Edit* pulldown menu is used to remove the highlighted application module member of the *Active Modules* list. Note that all active graphics objects must be removed before the application module used to generate their data can be removed.

The APEXRAD-APP Module

Model Name:	APEXRAD
Version:	15 September 1997; IGRF updates 2009
Developer:	Air Force Research Laboratory
References:	Bell, J.T., and M.S. Gussenhoven, APEXRAD Documentation, *PL-TR-97-2117* (1997), ADA 331633
	Gussenhoven, M.S., E.G. Mullen, D.A. Hardy, D. Madden, E. Holeman, D. Delorey, and F. Hanser, Low Altitude Edge of the Inner Radiation Belt: Dose Models from the APEX Satellite, *IEEE Trans. Nucl. Sci., 42*, 2035 (1995)
	Gussenhoven, M.S., E.G. Mullen, J.T. Bell, D. Madden, and E. Holeman, APEXRAD: Low Altitude Orbit Dose as a Function of Inclination, Magnetic Activity and Solar Cycle, *IEEE Trans. Nucl. Sci., 44*, 2161, (1997)
	Mullen, E.G., M.S. Gussenhoven, J.T. Bell, D. Madden, E. Holeman, and D. Delorey, Low Altitude Dose Measurements from APEX, CRRES, and DMSP, *Advances in Space Res., 21*, 1651, (1997)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

APEXRAD-APP Overview

The APEXRAD application and science modules are based on the PC program APEXRAD developed and released by the Air Force Research Laboratory. More information can be found in the APEXRAD Science Module section of this document.

The APEXRAD-APP module calculates satellite radiation dose accumulations behind four different thicknesses of aluminum (either slab or hemisphere) for user-specified orbits. Dose accumulation is predicted using empirical dose rate models created from data measured on the Advanced Photovoltaic and Electronics Experiment (APEX) which flew in a 362 x 2544 km elliptical orbit inclined at 70 degrees. These dose models have a higher position resolution at low altitudes than the previously released CRRESRAD models. The APEXRAD models give dose rates averaged over the entire APEX mission and for four different levels of magnetic disturbance, based on a 15 day (offset by 1 day) running average of the linear geomagnetic activity index Ap. APEXRAD is best applied to orbits with apogees less than 2500 km, perigees greater than 350 km, inclinations less than 60 degrees and for times during solar cycle minimum. It can be useful for orbits with higher inclinations or lower perigees, but the user must account for any dose that may be received outside the region covered by the model. For higher altitude orbits the use of CRRESRAD is recommended.

Note: The APEXRAD science module need NOT be run before APEXRAD-APP.

APEXRAD-APP Inputs

The inputs to the APEXRAD-APP module are the orbit elements needed to calculate the satellite orbit. The Environment Window for the APEXRAD-APP module is the same as that for the SATEL-APP module except that the *SMean* option is inactive and APEXRAD-APP is set to use the orbit propagator Lokangle. See the SATEL-APP Module documentation section for details. The IGRF/O-P magnetic field model is used with extrapolation beyond 2010.

APEXRAD-APP Outputs

The APEXRAD-APP module generates a return text window. Included in the text are the orbit elements and tables of the accumulated yearly dose (in units of rads silicon/yr) for all four thicknesses of aluminum shielding during four levels of magnetic activity. Also generated is a 1D Gridded Data Set giving the position of the satellite as a function of time that can be displayed using the Satellite graphics module. The *Show Text* button can be used to display the text window if it has been closed.

The BFIELD-APP Module

Model Name:	BFGEOS
Version:	4 June 2008
Developer:	Air Force Research Laboratory
References:	Hilmer, R.V., and G.-H. Voigt, A Magnetospheric Magnetic Field Model with Flexible Current Systems Driven by Independent Physical Parameters, *J. Geophys. Res., 100*, 5613 (1995)
	Huang, C.-L ., H.E. Spence, H.J. Singer, and N.A. Tsyganenko, A quantitative assessment of empirical magnetic field models at geosynchronous orbit during magnetic storms, *J. Geophys. Res., 113*, A04208, doi:10.1029/2007JA012623 (2008)
	Olson, W.P., and K.A. Pfitzer, A Quantitative Model of the Magnetospheric Magnetic Field, *J. Geophys. Res., 79*, 3739 (1974)
	Olson, W.P., and K.A. Pfitzer, Magnetospheric Magnetic Field Modeling, Annual Scientific Report, Air Force Office of Scientific Research contract F44620-75-C-0033, McDonnell Douglas Astronautics Co., Huntington Beach, CA (1977), ADA 037492
	Pfitzer, K.A., Improved Models of the Inner and Outer Radiation Belts, Scientific Report No. 1, *PL-TR-91-2187*, Phillips Laboratory, Hanscom AFB, MA (1991), ADA 242579
	Qin, Z., R.E. Denton, N.A. Tsyganenko, and S. Wolf, Solar wind parameters for magnetospheric magnetic field modeling, *Space Weather, 5, S11003*, doi:10:1029/2006SW000296 (2007)
	Tsyganenko, N.A., Global Quantitative Models of the Geomagnetic Field in the Cislunar Magnetosphere for Different Disturbance Levels, *Planet. Space Sci., 35*, 1347-1358 (1987)
	Tsyganenko, N.A., A Magnetospheric Magnetic Field Model with a Warped Tail Current Sheet, *Planet. Space Sci., 37*, 5-20 (1989)
	Tsyganenko, N.A., A model of the near magnetosphere with a dawn-dusk asymmetry, 1. Mathematical structure, *J. Geophys. Res., 107 (A8),* 1179, 10.029/2001JA000219 (2002a)
	Tsyganenko, N.A., A model of the near magnetosphere with a dawn-dusk asymmetry, 2. Parameterization and fitting to observations, *J. Geophys. Res., 107 (A8),* 1176, 10.029/2001JA000220 (2002b)
	Tsyganenko, N.A., and M.I. Sitnov, Modeling the dynamics of the inner magnetosphere during strong geomagnetic storms, *J. Geophys. Res., 110, A03208,* doi: 10.029/2004JA010798 (2005)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

BFIELD-APP Overview

The B-Field application generates maps of the magnetic field in the near-Earth space environment. It can be used to generate gridded data sets of magnetic field magnitudes, to trace field lines and to construct flux tubes. The application code was written by Robert V. Hilmer of AFRL. To trace magnetic field-lines originating from points along a satellite orbit track, the user should use BFOOTPRINT-APP.

B-FIELD Inputs

Inputs to the BFIELD-APP are needed to specify which type of data set to generate and which field models to implement.

The *Generate* section specifies the data sets to be generated when the B-FIELD application is run. The user may choose any combination of data set choices.

Gridded Data:	Choosing this option generates magnetic field GSM components and magnitude at each point on the grid specified under the *Grid Tool*.
MLAT Field Lines:	Choosing this option generates field lines emanating from constant (dipole) magnetic latitude. The user specifies the magnetic latitude, minimum magnetic local time, maximum magnetic local time (all at one Earth radius), and the number of local time steps in the MLAT Field Line Inputs section.
MLT Field Lines:	Choosing this option generates field lines starting at a constant magnetic local time. The user specifies the magnetic local time, minimum magnetic latitude, maximum magnetic latitude (all at one Earth radius) and the number of latitude steps in the MLT Field Line Inputs section.
Flux Tube:	Choosing this option generates field lines representing a flux tube. The user specifies either the geographic (latitude, longitude, altitude) or magnetic (MLAT, MLT, Radius) coordinates of the center of the footprint of the flux tube, a diameter and the number of field lines to generate in the Flux Tube Inputs section. If a single field line is requested or the diameter is zero then a single field line is constructed anchored at the footprint center. Magnetic dipole coordinates are also available.

The *Internal B-Field* section allows the user to specify which model to use for the Earth's internal magnetic field. The options are:

Dipole:	An Earth centered dipole field with the tilt determined by UT, Julian day, and year. The equatorial surface field is approximately 30750 nT.
IGRF(1945-2010):	The International Geomagnetic Reference Field. The coefficient set is chosen according to the time between the first day of 1945 and the last day of 2010. Code source: National Space Sciences Data Center (NSSDC).

Fast IGRF: A computationally faster truncated version of the IGRF field developed by Pfitzer (1991). The typical speed advantage is 7 to 8 times while the output differs from that of the full IGRF routine by no more than 0.1 nT.

The *External B-Field* section allows the user to specify which model to use for external contributions to the magnetic field. The options are:

None: No external field model is used.

Hilmer-Voigt: The external field model developed by *Hilmer and Voigt* [1995] is applied. Choosing this option requires additional inputs to be specified in the Hilmer-Voigt Options window that appears upon selection.

Olson-Pfitzer: The external field model developed by *Olson and Pfitzer* [1977] is applied.

Tsyganenko '89: The external field model developed by *Tsyganenko* [1989] is applied. There are two model versions: (1) The Kp driven model uses the Kp index from the *Global Parameters* section of the *Environments* window and (2) the AE driven model requires an AE range to be selected from the *Tsyganenko '89 Options* Window. Code source: NSSDC.

Tsyganenko '87: The external field model developed by *Tsyganenko* [1987] is applied using the "long" warped tail with no aberration. The Kp index is input from the *Global Parameters* section of the *Environment Window*.
Code source: NSSDC.

Tsyganenko '02 The external field model developed by *Tsyganenko* [2002a, 2002b] is applied (via subroutine T01_01 released date 8 August 2001; last updated 24 June 2006; code source: http://modelweb.gsfc.nasa.gov). The six basic model inputs include *Dst*, *IMF-*B_y, *IMF-*B_z, solar wind pressure *SW-Press* (nPa), and the coefficients denoted *G1* and *G2*. There are three methods for generating these six basic input parameters:

Current Dst 1-Hr IMF/SW Trends: In this option, the coefficients *G1* and *G2* are derived from a 1-hour time history of the IMF and the solar wind speed *SW-Vel* (km/s) [*Tsyganenko*, 2002a].

Read current values from VIRBO file: The six input parameters will be read from file *solarwind.dat* located in the directory $AFGS_HOME/models/data/BMODELS. This file currently contains values for 1963 – 2011 with average values listed to complete the remainder of 2009. Parameter updates for amending this file are available from the Virtual Radiation Belt Observatory (http://virbo.org). The parameters included here were copied from a file called "WGhour-v5.d" found in ftp://virbo.org/QinDenton/hour/merged/WGhour-v5.d.zip. After running the module, a status variable (equal to 0, 1, or 2) will appear in parentheses next to the each VIRBO

parameter read from file *solarwind.dat*. The file header provided by the original authors explains that the user should "note carefully: If the status variable is 2, the quantity you are using is fairly well determined. If it is 1, the value has some connection to measured values, but is not directly measured. These values are still better than just using an average value, but not as good as those with the status variable equal to 2. If the status variable is 0, the quantity is based on average quantities, and the values listed are no better than an average value. The lower the status variable, the less confident you should be in the value."

Current Dst, IMF, SW-Press, G1, G2: In this option, the user can manually enter the six basic model input parameters.

Tsyg-Sitnov '05 — The external field model developed by *Tsyganenko and Sitnov* [2005] is applied (via subroutine T04_s released date 25 March 2004; last updated 24 June 2006; code source: http://modelweb.gsfc.nasa.gov). The ten basic model inputs include *Dst*, *IMF-*B_y, *IMF-*B_z, solar wind pressure *SW-Press* (nPa), and the coefficients denoted *W1 - W6*. There are three methods for generating these ten basic input parameters:

Current Dst Multi-Hr IMF/SW Trends: In this option, the coefficients *W1-W6* are derived from a multi-hour time history of the IMF and the solar wind speed *SW-Vel* (km/s) and density *SW Den* (#/cm^3) [*Tsyganenko and Sitnov*, 2005].

Read current values from VIRBO file: The ten input parameters will be read from file *solarwind.dat* located in the directory $AFGS_HOME/models/data/BMODELS. For data file details, see the "Read current values from VIRBO file" portion of the *Tsyganenko '02* section above.

Current Dst, IMF, SW-Press, W1-W6: In this option, the user can manually enter the ten basic model input parameters.

The *MLAT Field Line Inputs* section allows the user to specify the parameters needed if the *MLAT Field Lines* option has been chosen. The inputs required to specify the field lines are:

MLAT: The constant magnetic latitude (dipole) specified in degrees from which to trace field lines.

MLT0, MLT1: The minimum and maximum magnetic local times specified in hours. Field lines will be traced at magnetic local times between *MLT0* and *MLT1*.

Steps: The number of field lines to trace (= *Steps*+1). This specifies the number of field lines to trace from *MLT0* to *MLT1*. Hence, field lines will be traced at $MLT = MLT0 + i * (MLT1 - MLT0) / Steps$ where i = 0 to *Steps*

The *MLT Field Line Inputs* section allows the user to specify the parameters needed if the *MLT Field Lines* option has been chosen. The inputs required to specify the field lines are:

MLT — The constant magnetic local time specified in hours from which to trace field lines.

MLAT0, MLAT1 — The minimum and maximum magnetic latitude (dipole) specified in degrees. Field lines will be traced at magnetic latitudes from *MLT0* to *MLT1*.

Steps — The number of field lines to trace (= *Steps*+1). This specifies the number of field lines to trace from *MLAT0* to *MLAT1*. Hence, field lines will be traced at *MLAT* = *MLAT0* + *i* * (*MLAT1* - *MLAT0*) / Steps where *i* = 0 to *Steps*

The *Flux Tube Inputs* section allows the user to specify the parameters needed if the *Flux Tube* has been chosen. Either *Geographic* or *Magnetic* coordinates can be selected by clicking the appropriate button. The inputs required to specify the flux tube are:

Lat, Long, Alt: — The geographic latitude, longitude and altitude of the center of the flux tube. Latitude and Longitude are input in degrees. Altitude is specified in kilometers above the Earth's surface.

MLAT, MLT, Rad: — The magnetic latitude, local time and geocentric radius of the center of the flux tube. *MLAT* is specified in degrees, *MLT* is specified in hours, and *Rad* is specified in Earth radii.

Diam: — The diameter of the flux tube specified in kilometers for geocentric coordinates and degrees for geomagnetic coordinates. The edges of the flux tube are specified at the same altitude(radius) as the center. If *Diam* = 0 then a single field line is drawn from the center location.

Steps: — The number of field lines to generate to represent the flux tube. The field lines will be traced from the boundary of a circle with diameter *Diam* centered at *Lat*, *Long*, *Alt*. If *Steps* = 1 then a single field line is drawn from *Lat, Long, Alt* or *MLAT, MLT, Rad* location.

Hilmer-Voigt Inputs

If the *Hilmer-Voigt External Field* is chosen, a popup window appears requesting further inputs. Several different input modes are available for the Hilmer-Voigt model,

Kp Only: — For this case, only the Environment window global Kp is used to drive the model. Note that the Hilmer-Voigt model in *Kp Only* mode only accepts Kp as an integer between 0 and 9. AF-GEOSpace will automatically convert the global Kp to an integer in this range. The value used will be displayed in the label next to *Kp Only*.

Standoff, Dst, EquatorwardEdge: — The user must choose from discrete values of the standoff distance, the *Dst* value, and the equatorward edge of the diffuse aurora at midnight. Choosing this input will sensitize the inputs at the right side of the Hilmer-Voigt '95 options window.

Vacuum Config: For the vacuum configuration, the standoff input box will be sensitized. There are no restrictions for standoff distance (other than Standoff > 0).

Combinations of input boxes at the right side of the Hilmer-Voigt '95 options window will be available according to the input mode setting. These boxes allow inputs of Dst, Equator Edge of the diffuse aurora at midnight and standoff distance to be selected. Because configurations representing all permutations of the Hilmer-Voigt input options do not exist (many are unphysical), the model status window will show the actual inputs used. If the parameters listed in the status window differ from those selected, then a configuration substitution occurred internally.

Dst: The value of *Dst* to use for the model. Used only in *Standoff, Dst, Equatorward Edge* input mode. Only discrete values of *Dst* are allowed.

Eq Edge: The latitude of the equatorward edge of the diffuse aurora at midnight. Used only in *Standoff, Dst, Equatorward Edge* input mode. Only discrete values of equatorward edge are allowed.

Standoff: The magnetopause standoff distance is specified in Re. This input is used by the *Vacuum Config* and *Standoff, Dst, Equatorward Edge* input modes. If in *Vacuum Config.* mode, then arbitrary values for the standoff distance can be introduced by editing the text box. If the input mode is *Standoff, Dst, Equatorward Edge*, then only discrete input values are allowed.

BFIELD-APP Outputs

Depending on the *Generate* options selected, the BFIELD application will produce (1) a 3D Gridded Data Set of the GSM coordinates and magnitude values of the B-Field, (2) a Field Line Data Set containing field line traces from a constant MLAT, (3) a Field Line Data Set containing field line traces from a constant MLT, and (4) a Field Line Data Set containing field line traces representing a flux tube. Outputs (2), (3), and (4) are displayed using the Field Lines graphic module. The dipole tilt angle is also calculated and appears in the model status window.

The BFOOTPRINT-APP Module (Static Only)

Model Name:	BFGEOS and LOKANGL
Version:	June 2008
Developer:	Air Force Research Laboratory
References:	(See the BFIELD-APP and SATEL-APP sections of this document)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

BFOOTPRINT-APP Overview

The BFOOTPRINT application traces geomagnetic field-lines from single user-specified points or from multiple points from along a satellite orbital track and determines their footprint locations on the Earth's surface. Magnetic field model options are identical to those offered in the BFIELD-APP module. Satellite orbits are determined using the LOKANGL orbit generator options in the SATEL-APP module.

BFOOTPRINT Inputs

The inputs to the BFOOTRINT-APP module include (1) the parameters needed to specify the geomagnetic field configuration and (2) locations from which to trace magnetic field lines, i.e., either single user-specified points or multiple points from an interval of a satellite orbit. Access to the required *Setup* input sections is controlled by the *Footprint Model* and *Satellite* options at the top of the Environment Window. The BFOOTPRINT-APP module can be run and/or updated while either *Setup* section is showing.

The *Setup: Footprint Model* button changes the lower portion of the Environment Window to show *Foot Line Input* and *B-Field Parameter* options.

Foot Line Input:

Geographic: Choosing this option generates a field line through a single *Geographic Point Coordinate*. The user specifies the point's Altitude (*Alt*) in km, Latitude (*Lat*) in degrees North, and Longitude (*Lon*) in degrees East.

Magnetic: Choosing this option generates a field line through a single *Magnetic Point Coordinate*. The user specifies the point's geocentric *Radius* in Earth Radii (RE), Magnetic Latitude (*MLAT*) in degrees North, and Magnetic Local Time (*MLT*) in hours.

From Satellite: Choosing this option generates field lines through multiple points along a satellite orbit interval defined by the following *Satellite Orbit Fractions and Steps* options.

Start Frac: The first trace will originate from the satellite's location at time = [*T_start* + (*Start Frac*)(*T_stop* - *T_start*)], e.g., *Start Frac* = 0.0 produces a trace at time *T_start*. Permitted value is from 0.0 and 1.0.

Stop Frac:	The last trace will originate from the satellite's location at time = [*T_start* + (*Stop Frac*)(*T_stop* - *T_start*)], e.g., *Stop Frac* = 1.0 produces a trace at time *T_stop*. Permitted value is from 0.0 and 1.0.
Steps:	The number of field lines to trace (100 maximum). Traces will be generated from orbit locations corresponding to times *Start Frac*, *Stop Frac*, and at equal time intervals between the two, i.e., = (*T_stop* - *T_start*)(*Stop Frac* - *Start Frac*)/(*Steps* - 1). If *Stop Frac* < *Start Frac*, then only a single field line trace from the location corresponding to *Stop Frac* will be determined.

Note: If this *From Satellite* option is selected, the user must use the *Setup: Satellite* option at the top of the Environment Window to define the orbit. To produce traces from particular points along an orbit, it is easiest to limit the interval using the orbit *T_start* and *T_stop* options accessible via *Setup: Satellite*.

B-Field Parameters: The geomagnetic field configuration is a combination of models representing the *Internal B-field* (i.e., *Centered Dipole*, *IGRF(1945-2010)*, or *Fast IGRF*) and *External B-field* (i.e., *None*, *Hilmer-Voigt '95*, *Olson-Pfitzer '77*, *Tsyganenko '89*, *'87, '02, and Tsyg-Sitnov '05*). Please refer to the BFIELD-APP Module section of this document for model details.

The *Setup: Satellite* button changes the lower portion of the Environment Window to show the standard set of *Ephemeris Data* inputs. See the *SATEL-APP* section of this document for details. The user must provide either orbital elements or select a satellite from files provided. Note that if the *SGP4* propagator is used, the orbit interval must be within a year of *T_ref* or the application will issue an error warning.

Note: This is a Static module, i.e., the global time is used to establish a single magnetic field configuration. If field lines from along a satellite track are to be calculated, higher accuracy will be achieved if orbit intervals are short and centered about the global time.

BFOOTPRINT-APP Outputs

The BFOOTPRINT application will produce a Field Line Data Set containing a field line trace through a single user-specified point defined in geographic or magnetic coordinates or field line traces from points (spaced equally in time) along a portion of a satellite orbit. The traces are displayed using the FIELD LINE graphics module. The *Show Footprints* button displays a list of field-line footprint locations on the Earth's surface given in Earth Radii (*rad*), degrees latitude (*lat*), and East Longitude (*lon*). Footprints determined by tracing in the direction parallel (anti-parallel) to the magnetic field are labeled *F1* (*F2*). Footprint positions of field lines traces that do not connect to the Earth, e.g., field lines map beyond the boundary of the magnetic field model, are assigned *rad*, *lat*, and *lon* values of zero.

If the *From Satellite* option is used, then a 1D Gridded Data Set of the position of the selected satellite as a function of time is produced that can be viewed using the SATELLITE graphics module. Single user-specified points are also viewed using the SATELLITE graphics module.

The CRRESELE-APP Module

Model Name: CRRESELE

Version: July 1995; IGRF updates 2009

Developer: Air Force Research Laboratory

References: Brautigam, D.H., and J. Bell, CRRESELE Documentation, *PL-TR-95-2128*, Phillips Laboratory, Hanscom AFB, MA (1995), ADA 301770

Brautigam, D.H., M.S. Gussenhoven, and E.G. Mullen, Quasi-static Model of Outer Zone Electrons, *IEEE Trans. Nucl. Sci., 39*, 1797-1803 (1992)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

CRRESELE-APP Overview

The CRRESELE science and application modules are based on the PC program CRRESELE developed and released by the Air Force Research Laboratory. More information on CRRESELE can be found in the CRRESELE Science Module section of this document.

The CRRESELE-APP module determines yearly electron omni-directional fluence (differential and integral) for ten energy intervals in the range 0.5-6.60 MeV. A user-specified orbit is traced through all of the eight different CRRESELE outer zone electron flux models to provide an estimate of electron fluence received by the satellite under a wide range of magnetospheric conditions. The differential and integral omni-directional fluences are calculated from the electron flux models as explained by this excerpt from the CRRESELE documentation:

> “To obtain the desired yearly differential omni-directional fluence and integral omni-directional fluence, the time spent in each spatial bin traversed by the user-specified orbit is first determined. It is important to realize that only those spatial bins within the bounds of the model (2.5 <= L <= 6.8 and 1 <= B/B0 <= 684.6) are used in the fluence calculation. For a given spatial bin, the differential omni-directional fluence [is calculated as the differential omni-directional flux multiplied by the time spent in the bin] and the integral omni-directional fluence for a given energy channel [is calculated from the product of the differential omni-directional fluence and the appropriate energy bandwidths by summing over all energy channels with energy greater than the given channel]. [...] The final reported fluences are calculated by performing the summation over all traversed bins (within the model bounds) and then multiplying by [the number of days in 1 year divided by the duration of the orbit trace in days]. [...] The percent of time spent by the orbit outside the model bounds is provided in the [output]. It should be stressed again that the calculated fluences are from the outer zone electron belt only. A low Earth polar orbit will pass within the model bounds only about 15% of the time, whereas a nearly geosynchronous orbit will remain within the model bounds nearly 100% of the time.”

Note: The CRRESELE science module need NOT be run before CRRESELE-APP.

CRRESELE-APP Inputs

The inputs to the CRRESELE-APP module are the orbit elements needed to calculate the satellite orbit. The Environment Window for the CRRESELE-APP module is the same as that for the SATEL-APP application except it is set to use the orbit propagator Lokangle. See the SATEL-APP Module section of the documentation for input descriptions. The IGRF/O-P magnetic field model is used with extrapolation beyond 2010.

CRRESELE-APP Outputs

The CRRESELE application generates a return text window that can be displayed using the *Show Text* button if it was closed. Included in the text are the orbit elements and tables of both the differential fluence (in #/cm^2-keV-yr) and integral omni-directional fluence (in #/cm^2-yr) calculated for all ten energy channels and all eight outer zone electron flux models. Also generated is a 1D Gridded Data Set giving the position of the satellite as a function of time that can be displayed using the Satellite graphics module.

Note that the "Model Number" values (*0, 1, 2, 3, 4, 5, 6*, and *7*) reported in the text window correspond to the eight *Ap15 Model Range* options (*5.0-7.5, 7.5-10.0, 10.0-15.0, 15.0-20.0, 20.0-25.0, 25.0-55.0, AVE*, and *MAX*) described in the CRRES Science Module section, respectively.

The CRRESPRO-APP Module

Model Name:	CRRESPRO
Version:	28 July 1994; IGRF updates 2009
Developer:	Air Force Research Laboratory
References:	Meffert, J.D., and M.S. Gussenhoven, CRRESPRO Documentation, *PL-TR-94-2218*, Phillips Laboratory, Hanscom AFB, MA (1994), ADA 284578
	Gussenhoven, M.S., E.G. Mullen, M.D. Violet, C. Hein, J. Bass, and D. Madden, CRRES High Energy Proton Flux Maps, *IEEE Trans. Nucl. Sci., 40*, 1450-1457 (1993)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

CRRESPRO-APP Overview

The CRRESPRO application and science modules are based on the PC program CRRESPRO developed and released by the Air Force Research Laboratory. More information on CRRESPRO can be found in the CRRESPRO Science Module section of this document. Note that the TPM-1-APP application module produces results similar to those of CRRESPRO-APP.

The CRRESPRO-APP module calculates proton omni-directional fluence (differential and integral) over the energy range 1-100 MeV for user specified orbits and quiet or active geophysical conditions. Fluences are calculated from the CRRES proton flux maps as explained by this excerpt from the CRRESPRO Documentation:

> "To calculate differential omni-directional fluences per year for an orbit input by the user, the time in seconds spent in each (L,B/B0) bin is calculated [...] and the differential flux for each bin is multiplied by the time in seconds spent in that bin. The figures in the individual bins are then summed [and] the resulting figure is then multiplied by seconds per year divided by the sum of time in seconds for all bins [including the time the orbit spends outside the model region]."

Integral omni-directional fluence for a given energy channel is calculated from the differential omni-directional fluence by summing over all energy channels with energy greater than the given channel (eliminating those with overlapping energy ranges, channels 5 and 15) and multiplying by appropriate bandwidths, as discussed in the CRRESPRO documentation.

Note: The CRRESPRO science module need NOT be run before CRRESPRO-APP.

CRRESPRO-APP Inputs

The inputs to the CRRESPRO-APP module are the orbit elements needed to calculate the satellite orbit. The Environment Window for the CRRESPRO-APP module is the same as that for the SATEL-APP application except CRRESPRO-APP is set to use the orbit propagator Lokangle. See the SATEL-APP Module section of the documentation for input descriptions. The IGRF/O-P magnetic field model is used with extrapolation beyond 2010.

CRRESPRO-APP Outputs

The CRRESPRO application module generates a return text window which can be displayed using the *Show Text* button if it has been closed. Included in the text are the orbit elements and tables of both the differential fluence (in #/cm^2-MeV-yr) and integral omni-directional fluence (in #/cm^2-yr) calculated for all 22 retained energy channels and for both active and quiet conditions. Also generated is a 1D Gridded Data Set giving the position of the satellite as a function of time that can be displayed using the Satellite graphics module.

The CRRESRAD-APP Module

Model Name: CRRESRAD

Version: 6 August 1992; IGRF updates 2009

Developer: Air Force Research Laboratory

References: Kearns, K.J., M.S. Gussenhoven, CRRESRAD Documentation, *PL-TR-92-2201*, Phillips Laboratory, Hanscom AFB, MA (1992), ADA 256673

Gussenhoven, M.S., E.G. Mullen, M. Sperry, K.J. Kerns, and J.B. Blake, The Effect of the March 1991 Storm on Accumulated Dose for Selected Satellite Orbits: CRRES Dose Models, *IEEE Trans. Nuc. Sci., 39*, 1765-1772 (1992)

Gussenhoven, M.S., E.G. Mullen, D.H. Brautigam, E. Holeman, C. Jordan, F. Hanser, and B. Dichter, Preliminary Comparison of Dose Measurements on CRRES to NASA Model Predictions, *IEEE Trans. Nucl. Sci., 38*, 1655-1662 (1991)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

CRRESRAD-APP Overview

The CRRESRAD application and science modules are based on the PC program CRRESRAD developed and released by the Air Force Research Laboratory. More information can be found in the CRRESRAD Science Module section of this document.

The CRRESRAD-APP module calculates expected satellite dose accumulation behind four different thicknesses of aluminum shielding for user specified orbits during quiet, active, or average geophysical activity levels. Dose accumulation is calculated from the CRRES dose rate maps for each of the four shielding domes (82.5, 232.5, 457.5, and 886.5 mils) and for each of the two dose rate detectors (HILET and LOLET) by determining the time in seconds that a specified orbit stays in a (L, B) coordinate bin and multiplying this time by the dose rate for this bin. These figures are then summed over the bins and multiplied by the number of seconds in a year divided by the sum of the time in seconds for all bins (including time the orbit spends outside the model region).

Note: The CRRESRAD science module need NOT be run before CRRESRAD-APP.

CRRESRAD-APP Inputs

The inputs to the CRRESRAD-APP module are the orbit elements needed to calculate the satellite orbit. The Environment Window for the CRRESRAD-APP module is the same as that for the SATEL-APP module except CRRESRAD-APP is set to use the orbit propagator Lokangle. See the SATEL-APP Module documentation section for details. The IGRF/O-P magnetic field model is used with extrapolation beyond 2010.

CRRESRAD-APP Outputs

The CRRESRAD-APP module generates a return text window that can be displayed using the *Show Text* button if it has been closed. Included in the text are the orbit elements and tables of the accumulated yearly dose (in units of rads silicon/yr) for all four shielding domes and both detectors. Also generated is a 1D Gridded Data Set giving the position of the satellite as a function of time that can be displayed using the Satellite graphics module.

The IONSCINT-G-APP Module

Model Name: GPS Version of the High Fidelity Ionospheric Scintillation Simulation Algorithm (IONSCINT-G)

Version: July 2009

Developer: AER, Inc., Boston College, and the Air Force Research Laboratory

References: (See the IONSCINT-G Science Module section of this document)

Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

IONSCINT-G-APP Overview

The IONSCINT-G Application Module generates a simulated time-based series of S4 scintillation values representing conditions between a user-specified platform position and either a satellite. An option to use a fixed targeting angle (defined in azimuth and elevation angle) is also provided. The IONSCINT-G-APP simulation options are identical to those offered in the science module based on the same model (see complete details in the IONSCINT-G Science Module chapter). Satellite orbits are determined using the LOKANGL orbit generator options from within the SATEL-APP module.

IONSCINT-G-APP Inputs

The IONSCINT-G Application Module requires four types of inputs used to define (1) a static run time or dynamic run time interval, (2) scintillation database options to characterize the type of scenario desired along with a large random number seed (typically a 5-digit number), (3) the static platform position, and (4) either orbital details for defining the platform-satellite link or an azimuth/elevation targeting angle for defining a fixed look direction from the specified platform position. Access to the required *Setup* input sections is controlled by the *Satellite* and *Ionscint-G* options at the top of the Environment Window. The IONSCINT-G-APP module can be run and/or updated while either *Setup* section is showing. The following inputs are required.

Global Parameters: Year, Day, UT (Kp, SSN, F10.7, and Ap are not used).

The *Setup: Satellite* button changes the lower portion of the Environment Window to show the standard set of *Ephemeris Data* inputs and is fixed to use the LOKANGL propagator. See the *SATEL-APP* section of this document for details. In *Static* mode, the *T_start* and *T_stop* values will correspond to a 24-hour interval starting from the *Global Start* time. In *Dynamic* mode, those same values will reflect the user-specified *Global Start* and *End* times of the run. The S4 scintillation index will be calculated for the satellite-platform link at intervals specified in the *Time Step(s)* text box.

The *Setup: Ionscint-G* button changes the lower portion of the Environment Window to show *Ionscint-G Model Parameters* options which match those of the IONSCINT-G Science Module, namely

Scintillation Database Options: Scenarios are generated from the scintillation database using an input solar activity level and four related selection modifiers, namely

Sunspot Activity Level: Scintillation scenarios corresponding to four different levels of solar activity as defined by sunspot number (SSN) are represented. It should be noted that no significant scintillation at GPS frequencies occurs at solar minimum and “worst case” scenarios are associated with maximum SSN values.

1 = Low (10-30): This SSN range represents solar minimum conditions.

2 = Moderate (50-75): This SSN range represents conditions during the ramp up or down from solar maximum.

3 = High (85-100): This SSN range represents conditions from a “low-activity” maximum.

4 = Maximum (100-120): This SSN range represents conditions from a “high-activity” maximum.

Use Seasonal Climatology: This option provides the most realistic representation of the seasonal dependence of scintillation as a function of longitude. If the occurrence of scintillation is desired at all longitudes regardless of scintillation season, then uncheck this option. Note that quiet scintillation-free nights can still occur even with this option unchecked.

Use Only Top 10% Scintillation Scenarios: Selecting this option highlights the “worst” of the possible scenarios, i.e., it restricts scenario selection to be made randomly from only those portions of the database representing the top 10% of nights based on the total time of active scintillation per night. If left unchecked, then scenario sets will be chosen randomly from all in-season nights for the chosen solar activity level.

Retain Generated Random Number Seed Between Runs: Each time a new IONSCINT-G entry appears in the Active Modules list, e.g., *SciIonScintg0*, a new random number is placed in the text box to the right of the next input line. Each run utilizes the random number seed that is visible **before** the run is made. This value is used to randomize the selection of scenario sets from the appropriate solar activity level section of the database. For a given set of activity settings, using the same number seed will cause the same scintillation scenario to be generated. Select this option to retain use of the random number seed for additional runs. If neither this nor the next option is checked, then a *Run/Update* will place a new random

number seed in the text box (to be used for the next run!). If you complete a run without checking this option and did not record the number seed, you can recover the value used in your last run from file *C:\TEMP\SciIonScintg#\IONSCINTG.OUT* (assuming default scratch directory C:\TEMP).

Specify and Retain Random Number Seed: Select this option and edit the number seed value in the text box to retain use of the number seed for the current and future runs. Using the same input seed will cause the same scintillation scenario to be generated. To recreate the same scenario for more than one *Platform Position*, perform additional IONSCINT-G Science Module runs using the same *Random Number Seed* for each platform location.

Platform Position: The Platform Position defines the fixed reference position used for all GPS scintillation scenario calculations. Note that there will be no scintillation directly overhead (i.e., at the center of the skymap viewed with the IONSCINT-G graphic module) if the platform is placed at a magnetic latitude poleward of 30 degrees. The location is input in geographic coordinates assuming a spherical Earth, namely

Latitude: The platform's North latitude in degrees.

Longitude: The platform's East longitude in degrees (±360°).

Altitude (km): The platform's altitude in kilometers above the Earth's surface.

Use Fixed Targeting Angles: This option causes the module to display scintillation output for a fixed location in the sky as viewed from the *Platform Position* defined above. Note that a satellite selection must still be made as the timing inputs (*T_start, T_stop*, and *Time Step(s)*) from the *Setup: Satellite* settings are still required. Any arbitrary satellite may be used for this purpose, but note that the "name" to appear in plots comes from the *Sat Name* field in the *Setup:Satellite* settings so to eliminate confusion it should be edited to read something appropriate like "Platform1".

Azimuth(Deg): Azimuth angle in degrees as measured from the *Platform Position* (0° is North, 90° is East, etc.).

Elevation(Deg): Elevation angle in degrees as measured from the *Platform Position* (90° is zenith).

Notes: The *File* menu *Save Model/Open Model* features work only when either the *Retain Generated Random Number Seed Between Runs* or the *Specify and Retain Random Number Seed* option has been used.

IONSCINT-G-APP Outputs

The IONSCINT-G-APP module generates a time series of the S4 scintillation index representing the changing environment between the platform position and either a satellite or fixed GPS target location. The S4 index, with values ranging from 0.0 to 1.0, is a dimensionless quantity representing the normalized standard deviation of the signal intensity. The scintillation index (*S4Index*), azimuth and elevation angles, and local time in hours (*LocalTimeHrs*) can be plotted as a function of time in a 1D window by using the *Orbit Probe* graphics module. A tabulated version of the output can be found in file C:\TEMP\AppIonScintg#*IONSCINTG.OUT* (assuming default scratch directory C:\TEMP). If the *Platform Position* is displayed in a 3D window using the *Station* graphics module when tracking a satellite, then the *Satellite* and *Link* graphics modules can be used to better visualize when a satellite is viewable from the specified platform. Note that use of the *Station* graphics module for this situation will require converting the platform altitude units from kilometers to Earth radii, i.e., Alt(Re) ~ 1.0 + Alt(km)/6370.

Hint: To establish a context for interpreting the S4 scintillation time profiles generated for a given platform-satellite link using this module, the user should also run the IONSCINT-G Science Module for the same time period using the same fixed *Platform Position* and *Scintillation Database Options* settings.

The LET-APP Module

Model Name:	CRRES/SPACERAD Heavy Ion Model of the Environment (CHIME) and CRRESPRO
Version:	3.5 (December 1995)
Developer:	Lockheed Martin Advanced Technology Center and AFRL, adapted to AF-GEOSpace by Radex, Inc. (now AER, Inc.)
References:	Chenette, D.L., J.D. Tobin, S.P. Geller, CRRES/SPACERAD Heavy Ion Model of the Environment, CHIME, *PL-TR-95-2152*, Phillips Laboratory, Hanscom AFB, MA (1995) (User's guide for Version 3.5), ADA 321996
	Chenette, D.L., J. Chen, E. Clayton, T.G. Guzik, J.P. Wefel, M. Garcia-Munoz, C. Lopate, K.R. Pyle, K.P. Ray, E.G. Mullen, D.A. Hardy, The CRRES/SPACRAD Heavy Ion Model of the Environment (CHIME) for Cosmic Ray and Solar Particle Effects on Electronic and Biological Systems in Space, *IEEE Trans. Nucl. Sci., 41*, 2332-2339 (1994)
	Feynman, J., G. Spitale, J. Wang, and S. Gabriel, Interplanetary Proton Fluence Model: JPL 1991, *J. Geophys. Res., 98*, 13281 (1993)
	Meffert, J.D., and M.S. Gussenhoven, CRRESPRO Documentation, *PL-TR-94-2218*, Phillips Laboratory, Hanscom AFB, MA (1994), ADA 284578

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

LET-APP Overview

The Linear Energy Transfer (LET) Application Module and CRRES Heavy Ion Model of the near-Earth Space Environment (CHIME) Science Module are based on the PC program CHIME (with modifications) developed and released under the auspices of the Air Force Research Laboratory. More information on CHIME can be found in the CHIME Science Module section of this document.

The LET-APP Module calculates the LET spectra and associated Single-particle Event Upset (SEU) rate in an electronic device for a user-specified location or orbit. In addition to the Galactic Cosmic Rays (GCR), Anomalous Component (AC), and Solar Energetic Particles (SEP) modeled in the original CHIME, AF-GEOSpace provides the capability to include trapped protons, as specified by the CRRESPRO model (see the CRRESPRO Science Module section of this document), in the calculation of LET spectra and SEU rates. The importance of the LET spectra and method of determination are described as follows in the CHIME User's Manual:

> "For the purposes of estimating single-particle upset effects (including latchup), the heavy ion flux distributions as a function of particle type and energy are transformed into distributions as a function of the ion's linear energy transfer (LET). The LET is the energy lost by an ion and deposited into the target material per unit distance along the ion's path. LET generally increases with the atomic number of the ion (Z) and generally decreases with increasing velocity (V) approximately as Z^2V^{-2} (except at low and high

velocities where atomic effects and relativistic effects, respectively, become important). Thus a faster iron ion and a slower oxygen ion can have the same LET and, by assumption, the same ability to produce a single event upset in a specific device. The LET spectrum is a convenient way to integrate and keep track of the contributions of the various ion species and energies, ordered according to LET."

> "The LET spectrum calculator in CHIME employs an integral method and a two-part (shield and target) spherical geometry model. The thickness of the shield and the target are specified by the user in one of several column density units: milligrams per square centimeters (mg cm^{-2}), mils of aluminum equivalent, or microns of silicon. Since the range of an ion depends on the density of the target and only weakly on the target composition, the mass density option (mg cm^{-2}) permits the model to be used with different materials, e.g., GaAs.
>
> Working from the sensitive region out, and for each ion species, minimum and maximum incident ion energies are calculated corresponding to pre-defined LET thresholds. At each threshold LET, the integral LET spectrum is calculated by integrating the heavy ion flux spectrum over this energy range and summing over all particle species. The method and its results have been described in greater detail by *Chennette et al.* (1994)."

The LET spectrum is calculated both for the interplanetary flux environment model and for the near-Earth flux distribution, shielded by the effects of the Earth and its magnetic field. For the GCR, AC, and SEP, the interplanetary LET spectra will always be a "worst case" in terms of energy deposition. If the trapped proton option is selected, both the interplanetary and shielded LET spectra are modified to include the trapped proton fluxes corresponding to the user-specified orbit or location. To compute the geomagnetically shielded fluxes used in the LET calculation, a geomagnetic filter function is computed (see CHIME Science Module) for either the user-specified location or as an average over a user-specified orbit. This filter function is then applied to the GCR, AC, and SEP particle spectra used in the LET spectra computation. For the trapped protons, the LET spectrum is calculated separately at each point along an orbit and then averaged before being added to the total LET spectra (the limiting case is a single point if a location is specified).

The method for determining SEU rates is described in the CHIME User's Manual as follows:

> "To calculate a single-particle upset rate, CHIME combines the LET spectrum, calculated as described above, together with user specifications or measurements of the upset cross section, and a model for the geometry for a specific device, and performs a numerical integration. This procedure incorporates a rectangular parallelepiped model like that of *Pickel and Blandford* [*IEEE Trans. Nuc. Sci., NS-27*, 1006, 1980] to estimate the geomagnetic factor of the sensitive region as a function of path length. It provides a way to allow the user to input a measured upset cross-section (as a function of LET) as an improvement on the "step function" approximation. The only restriction on this tabulation is that it must be monotonic non-decreasing with increasing LET. This method and its sensitivity to assumptions of the geometry model have been described by *Shoga et al.* [*IEEE Trans. Nuc. Sci., NS-34*, 1256, 1987]. It is a direct application of a few simple geometrical concepts."

> "The upset rate is determined as the rate at which energetic heavy ions in the space radiation environment can deposit more than a certain minimum amount of energy into a specific volume. The minimum energy deposit required to cause an upset is called the upset threshold. The specific volume is the sensitive volume of a cell in the device. The single-particle upset rate is determined from the product of the local particle flux or fluence and the geometrical factor presented by the sensitive volume."

In LET-APP the parameters of the on-board microelectronic device can be specified in the window or read from a device file. The user is urged to consult the CHIME User's Manual for more details of the SEU rate calculation and required formats for the device input files.

Note: The CHIME Science Module need NOT be run before the LET-APP module.

LET-APP Inputs

Input to the LET-APP application comprises the inputs required to run the CHIME model, as adapted from the PC version. Several methods for inputting variables are available. The input window is logically divided into three areas: an environment specification section, a satellite location and/or microelectronic device section, and an auxiliary section for controlling module output.

Specify Environment:

GCR/AC Flux: Several methods for generating cosmic ray fluxes (Galactic Cosmic Rays/Anomalous Component Spectra) are provided. The options are:

- Off: No cosmic ray fluxes generated.
- Modulation: CHIME provides fluxes corresponding to the *Level* (entered in the text box, approximate range: 400 to 1600 megavolts) of solar modulation selected from a full range of monthly values over the period 1970-2010.
- Period: CHIME computes the average of the fluxes for each ion species over the user-specified time interval entered in the *Year 1*, *Day 1*, *Year 2*, and *Day 2* text boxes activated when this option is selected. Tabulated monthly values of the solar modulation parameter for the period 1970-2010 are used.

SEP Event: The CHIME model provides several models for specifying the flux or fluence of heavy ions originating at the Sun as a result of solar energetic particle (SEP) events. The options are:

- Off: No SEP event related flux/fluence is generated.
- March 91 Peak: Model based on peak CRRES measurements from the March 1991 event
- June 91 Peak: Model based on peak CRRES measurements from the June 1991 event

March 91 Ave: Model based on average CRRES measurements from the March 1991 event

June 91 Ave: Model based on average CRRES measurements from the June 1991 event

JPL 1991 Model: Models based on statistical distributions of solar proton event intensities (JPL 1991, *Feynmann et al.,* [1993]). It provides the proton fluence that would be exceeded at a probability level of occurrence (*Pr*), or confidence level, from 50% to 0.1%. If the *Flux Inputs* option *Off* or *Period* is selected above, then fluxes are calculated from the fluences using the user-specified time interval. If *Modulation* is selected as the *GCR/AC Flux* option, then a random period of 1 year is used.

Atomic Z: Two ranges for the ion species atomic number are offered, the full range (*1 to 92*) or a reduced range (*1 to 30*) may be used to save calculation time. If the full range is specified, the code uses tabulated values for hydrogen (Z=1) to nickel (Z=28) and all ions heavier than nickel are modeled using abundance ratios to iron.

Note: The cosmic ray flux input and solar event options are identical to those used in the CHIME Science Module.

Trapped Protons: Two models of trapped protons in the radiation belts corresponding to a quiet and active period, *CRRESPRO Quiet* and *Active*, are available (see CRRESPRO Documentation). The CRRESPRO flux data are read in for all available energies and incorporated into the CHIME system, using the same LET and SEU algorithms as for the cosmic ray protons.

Satellite/Device: There is a single row of options for selecting the satellite location and another for specifying the device.

Sat. Location: Input the satellite location as a single point or specify an orbit:

Single Point: The pop-up menu for the *Single Point* option asks for the satellite's altitude (km), latitude (degrees), and longitude (degrees).

Orbit: While not dynamic LET-APP permits the entry of satellite orbits as input. The orbit elements can be of two types:

Mean elements: These are the same as the elements that are normally read in by the SATEL-APP module, except there are no derivative or drag terms.

Chime elements: These simple elements represent the original inputs to the CHIME propagator and consist of the above

Mean elements, except that the mean anomaly is fixed at zero, so the reference time becomes the time of perigee, and the eccentricity and mean motion are replaced by altitudes for apogee and perigee.

Entering a set of *Mean elements* and then selecting the *Chime elements* toggle effects a translation to Chime elements. The *Default* button sets default orbit element values taken from *Meffert and Gussenhoven* [1994].

Note: The CHIME simple elements are listed as those parameters differing from the mean elements (right column) and those in common with the mean elements (left, highlighted). If entering *Mean elements*, one must convert to CHIME elements (by selecting the *Chime elements* toggle) before running because the CHIME propagator uses only the CHIME simple elements. A run error will occur if either (1) the orbit interval designated by *T_start* and *T_stop* is not within ± 1 year of *T_ref* or (2) more than approximately 3000 steps are calculated, e.g., running for more than ~3.47 days at 100 seconds per step.

From File: The *From File* button enables one to read in an input file containing mean orbital elements, in analogy to the SATEL-APP module. The mean elements are automatically converted to the equivalent simple elements for use by the CHIME propagator. The *Update* button ensures that the start, stop times and intervals are up to date. The *Orbit* popup window is automatically updated to show the parameters that were read. Note that a run error will occur if the orbit interval designated by *T_start* and *T_stop* is not within ± 1 year of the reference time listed next to the satellite name in the Chime Satellite File Options popup window.

SEU Device: The on-board microelectronic device can be specified by individual parameters or from a device file:

Parameters: The pop-up menu sets the device parameters as required for a single energy deposit SEU calculation. They include LET *Threshold*, *Upset cross-section*, number of *Bits per device*, *sensitive region* dimensions (*X* and *Y* are transverse, *Z* is depth) and *Density of material*. The *Default* button sets default parameter values taken from *Meffert and Gussenhoven* [1994].

From File: The pop-up presents a file selection menu. Files listed (in $AFGS_HOME\models\data\CHIME\devices) are those that came with the PC distribution. They contain

detailed upset cross-sections versus LET, for input into the calculation of integrated SEU rates.

Thickness: The pop-up menu sets the *Shield* and *Target* thicknesses. The units for each can be toggled between three choices: *mg/cm²*, *mils Al,* or *microns Si*. The *Default* button sets default thickness values from *Meffert and Gussenhoven* [1994].

Let Params: The pop-up menu sets minimum (*LET MIN*), maximum (*LET MAX*), and number of points (*NLETS*) for the LET spectrum. The *Default* button sets default spectrum parameter values from *Meffert and Gussenhoven* [1994].

LET-APP Outputs

The LET application outputs a summary text file for the selected case. The text file may be accessed by three toggle options. For each option, hit the *Display Text* button to update and display the current window:

SEU: Shows the final SEU rate for the case. The results are presented in two forms: a "worst case" which has the geometrically unshielded cosmic ray and/or solar flare rate (wo_Bgeo) along with any trapped proton contributions and a "best case" which is the same except that geometrically shielded cosmic/solar particles (w_Bgeo) are used. If the trapped protons are not included, then the rates should be the same as for the original PC version (there called interplanetary and geomagnetically shielded rates).

LET: This describes the two LET spectra that are used as input to the SEU rate calculation. The two flux columns represent the "worst/best" case results.

LET/TRAPPED: This contains the original PC version cosmic ray and/or solar flare LET geometrically unshielded and shielded components, and in a separate column, the trapped proton LET contribution.

Options *SEU* and *LET* above are, with some minor changes, the same as the output printed by the PC version of CHIME in the .SEU and .LET files.

Hit the *Display Text* button to update and display the current text window.

LET-APP outputs a 1D plot of the LET spectrum (see above) in the form of a log-log function, for the selected case. Hit the *Display Plot* button to display the 1D plot. If inputs are changed and the module is rerun, then the labels in the plot can be updated by again using the *Display Plot* button. The LET spectrum represents the total flux of particles of all types with an energy deposit per thickness ($MeV/mg/cm^2$) larger than the threshold for the bin. The two data lines represent the "worst/best" case LET results, as described above. Note that if the JPL solar flare model is chosen, flux is replaced by fluence.

The *Plot Options* button provides a menu for modifying the X and Y axes of the 1D plot.

The LET application also outputs a 1D Gridded Data Set of the position of the satellite as a function of time that can be displayed using the Satellite graphics module. The orbits can be single points or a complete trajectory, as calculated by the CHIME propagator.

The METEOR IMPACT-APP Module

Model Name:	Meteor Impact Map Model
Version:	February 2004
Developer:	Radex, Inc. (now AER, Inc.) and the Air Force Research Laboratory
References:	(see reference lists in the manual sections entitled "The METEOR IMPACT MAP Science Module" and "The SATEL-APP Module")

Note: It is recommended that AF-GEOSpace users read and understand the original model documentation and descriptive articles before using the models.

METEOR IMPACT-APP Overview

The METEOR IMPACT application module is based on the Meteor Impact Map Model. More information on the model can be found in the METEOR IMPACT MAP Science Module section of this document. If used in dynamic mode, the METEOR IMPACT MAP Science Module can certainly be used in combination with SATEL-APP to provide a rough measure of the hourly meteor impact rate along a satellite orbit, but the procedure is very inefficient. To increase both efficiency and accuracy, METEOR IMPACT-APP was developed to calculate the same impact parameter as a function of time only along a user-specified orbit. This feature enables the user to see meteor flux variations at the satellite owing to both position changes, e.g., observed fluxes decrease when blocked by the Earth, and shower and storm temporal variations. This application also calculates the probabilities of a satellite being damaged by meteor shower particle impacts over a period of time.

Note: The METEOR IMPACT MAP science module need NOT be run before METEOR IMPACT-APP.

METEOR IMPACT-APP Inputs

The inputs to the METEOR IMPACT-APP module include both the orbit elements needed to calculate the satellite orbit and the parameters needed to specify concurrent meteor showers and storms. While the meteor impact portion of the application will run using the default settings, *the user must provide orbital elements or select a satellite from file for a successful run*. Access to the two groups of inputs is provided in the *Setup* section at the top of the user interface, namely

Satellite: The *Satellite* button changes the lower portion of the Environment Window to show the standard set of *Ephemeris Data* inputs. See the *SATEL-APP* section of this document for details. The user must provide either orbital elements or select a satellite from files provided. Note that if the *SGP4* propagator is used, the orbit interval must be within a year of *T_ref* or the application will issue an error warning.

Meteor Impact Model: The *Meteor Impact Model* button changes the lower portion of the Environment Window to show meteor shower and storm input options identical to those described in the METEOR IMPACT MAP Science Module section of this document.

METEOR IMPACT-APP Outputs

The METEOR IMPACT application module returns a 1D Gridded Data Set representing the position of the satellite and the hourly impact rate and cumulative probability of being impacted by a meteor. To view the impact rate or probability output as a function of time in a 1D graphics window, for example, use the ORBIT PROBE graphics module and select the *Path/Abscissa* button option *AppMeteorImpact: Time* and the *Data/Ordinate* button options *AppMeteorImpact: Hourly Impact* or *CumProb*.

The NASAELE-APP Module

Model Name:	NASA Trapped Electron Model AE-8
Version:	National Space Science Data Center (NSSDC) Data Set PT-11B, Oct 1987; IGRF updates 2009
Developer:	NASA/NSSDC (distributed in AF-GEOSpace with permission)
References:	Vette, J.I., The AE-8 Trapped Electron Model Environment, *NSSDC/WDC-A-RS 91-24* (1991)
	Vette, J.I., The NASA/National Space Science Data Center Trapped Radiation Environment Model Program (1964-1991), *NSSDC/WDC-A-RS 91-29* (1991)
	Jordan, C.E., NASA Radiation Belt Models AP-8 and AE-8, *GL-TR-89-0267*, Geophysics Laboratory, Hanscom AFB, MA (1989), ADA 223660

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

NASAELE-APP Overview

The NASAELE-APP module determines yearly electron omni-directional fluence (differential and integral) for ten energy intervals in the range 0.65-5.75 MeV. A user-specified orbit is traced through the two different NASAELE outer zone electron flux models (min and max), at each energy, to provide an estimate of electron fluence received by the satellite under a wide range of magnetospheric conditions. The differential and integral omni-directional fluences are calculated using the same method employed by the CRRESELE-APP module.

Note: The NASAELE science module need NOT be run before NASAELE-APP.

NASAELE-APP Inputs

The inputs to the NASAELE-APP module are the orbit elements needed to calculate the satellite orbit. The Environment Window for the NASAELE-APP module is the same as that for the SATEL-APP application except NASAELE-APP is set to use the orbit propagator Lokangle. See the SATEL-APP Module section of the documentation for input descriptions. The IGRF/O-P magnetic field model is used with extrapolation beyond 2010.

NASAELE-APP Outputs

The NASAELE application generates a return text window that can be displayed using the *Show Text* button if it was closed. Included in the text are the orbit elements and tables of both the differential and integral omni-directional fluence (in units of #/(cm^2 keV yr) and #/(cm^2 yr), respectively) calculated for all ten energy channels and two outer zone electron flux models. Also generated is a 1D Gridded Data Set giving the position of the satellite as a function of time that can be displayed using the Satellite graphics module.

The NASAPRO-APP Module

Model Name:	NASA Trapped Proton Model AP-8
Version:	National Space Science Data Center (NSSDC) Data Set PT-11B, Oct 1987; IGRF updates 2009
Developer:	NASA/NSSDC (distributed in AF-GEOSpace with permission)
References:	Vette, J.I., The AE-8 Trapped Electron Model Environment, *NSSDC/WDC-A-RS 91-24* (1991)
	Vette, J.I., The NASA/National Space Science Data Center Trapped Radiation Environment Model Program (1964-1991), *NSSDC/WDC-A-RS 91-29* (1991)
	Jordan, C.E., NASA Radiation Belt Models AP-8 and AE-8, *GL-TR-89-0267*, Geophysics Laboratory, Hanscom AFB, MA (1989), ADA 223660

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

NASAPRO-APP Overview

The NASAPRO-APP module calculates yearly proton omni-directional fluence (differential and integral) over the energy range 1.5-81.3 MeV for user specified orbits and through two different NASAPRO flux models (AP-8 min and max). Fluences are calculated from the NASA proton flux maps using the same method employed by the CRRESPRO-APP module. Integral omni-directional fluence for a given energy channel is calculated from the differential omni-directional fluence by summing over all energy channels with energy greater than the given channel and multiplying by appropriate bandwidths.

Note: The NASAPRO science module need NOT be run before NASAPRO-APP.

NASAPRO-APP Inputs

The inputs to the NASAPRO-APP module are the orbit elements needed to calculate the satellite orbit and the Environment Window is the same as that for the SATEL-APP application except NASAPRO-APP is set to use the orbit propagator Lokangle. See the SATEL-APP Module section of the documentation for input descriptions. The IGRF/O-P magnetic field model is used with extrapolation beyond 2010.

NASAPRO-APP Outputs

The NASAPRO application module generates a return text window which can be displayed using the *Show Text* button if it has been closed. Included in the text are the orbit elements and tables of both the differential and integral omni-directional fluences (in units of #/(cm^2 MeV yr) and #/(cm^2 yr), respectively) calculated for all 22 energy channels and for both active and quiet conditions. Also generated is a 1D Gridded Data Set giving the position of the satellite as a function of time that can be displayed using the Satellite graphics module.

The RAYTRACE-APP Module

Model Name:	RAYTRACE
Version:	November 2001
Developer:	Radex, Inc. (now AER, Inc.) and Air Force Research Laboratory
References:	Coleman, C.J., A General Purpose Ionosphere Ray Tracing Procedure, *Report SRL0131TR*, Defence Science and Technology Organization, Australia (1993)
	Daniell, R.E., Jr., L.D. Brown, D.N. Anderson, M.W. Fox, P.H. Doherty, D.T. Decker, J.J. Sojka, and R.W. Schunk, Parameterized Ionospheric Model: A Global Ionospheric Parameterization Based on First Principles Models, *Radio Sci., 30,* 1499-1510 (1995)
	Jones, R.M., and J.J. Stephenson, A Versatile Three-Dimensional Ray Tracing Computer Program for Radio Waves in the Ionosphere, *OT Report 75-76*, US Govt. Printing Office, Washington, DC 20402 (1975)

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

Overview

Ray tracing allows the user to plot the behavior of rays in an ionosphere specified by a PIM data set. The PIM science module must be run before the ray tracing application can be used. When PIM is run in dynamic mode, this application will perform the same ray trace calculations for each time frame of the dynamic PIM output using a fixed set of transmitter coordinates and frequency/elevation properties. Transmitter coordinates and selected ray frequency and elevation ranges are submitted to the Australian 2D ray tracing algorithm [*Coleman*, 1993] or the Jones-Stephenson 3D ray trace model [*Jones and Stephenson*, 1975] and the resulting ray traces can be viewed. The viewing options include a special 1D display window activated from within the Ray Tracing Application or use of the Ray Trace Graphics Module within a standard AF-GEOSpace 3D window.

Ray Tracing Application Inputs

Dynamic PIM files must have time extension to work with RAYTRACE-APP

Model:	The plot type field determines which ray features are displayed.	
	Australian 2D:	The *Australian 2D* model algorithm [*Coleman*, 1993] provides the ability to plot rays along an arbitrary azimuth. All rays generated remain in the same plane.
	Jones-Stephenson 3D:	*The Jones-Stephenson 3D* model algorithm [*Jones and Stephenson*, 1975] provides the ability to plot rays in arbitrary directions. Rays generated do not necessarily remain within the same plane.

Freq (MHz): Ray traces at one or more frequencies can be performed simultaneously. *Freq (MHz)* options include:

- Single: The single frequency option requires that a single frequency value given in MHz be entered in the *Single* text box.
- Multi: The multi-frequency option requires that a frequency range and increment be specified.
  - From: The minimum frequency value in MHz.
  - To: The maximum frequency value in MHz.
  - Step: The size in MHz of the frequency steps to be taken starting at the *From* value, e.g., if *From* = 1, *To* = 5, and *Step* = 2 then traces will be calculated at 1, 3, and 5 MHz for each elevation.

Elev (deg): Ray traces at one or more elevation angles can be performed simultaneously. Elevation is an indication of initial ray direction measured in degrees relative to the horizon with elevation equal to 90 degrees representing zenith. *Elev (deg)* options include:

- Single: The single elevation angle option requires that a single elevation angle value given in degrees be entered in the *Single* text box.
- Multi: The multi-elevation angle option requires that an elevation angle range and increment be specified.
  - From: The minimum elevation angle value in degrees.
  - To: The maximum elevation angle value in degrees.
  - Step: The size in degrees of the elevation steps to be taken starting at the *From* value, e.g., if *From* = 10, *To* = 16, and *Step* = 2 then traces will be calculated at 10, 12, 14, and 16 degrees for each frequency.

Note: Up to 25 rays can be traced per application. This fact should be taken into consideration when *Freq (MHz)* and *Elev (deg)* selections are made.

Azimuth: The *Azimuth* value specifies the initial angle of the rays to be traced with azimuth = 0 indicating a northward traveling ray.

Range(1000 km): The *Range* value specifies the maximum range from the transmitter location that a ray will be traced. Note: Results will change if the *Range* is changed because the ray-trace step-size is a function of this input.

Max Hops: The *Max Hops* value specifies the maximum number of hops or bounces a traced ray can have as it refracts off of the ionospheric plasma and reflects off of the ground.

Transmitter Location: *Transmitter Location* option controls the coordinates for a ground-based transmitter. The transmitter altitude is fixed equal to zero.

Lat: The *Lat* text box is used to set the latitude location in degrees of the transmitter.

Lon: The *Lon* text box is used to set the longitude in degrees of the transmitter.

Open Pim File: The *Open Pim File* button is used to select generated PIM data before running the ray trace application. Select *Run/Update* from the *Edit* menu only after selecting the PIM data. If PIM was run in static mode, then the user should select the *pim_pud.out* (default name) file from a PIM directory located in the directory containing the AF-GEOSpace executable, e.g., select *(Scratch Directory)\SciPim# \pim_pud.out*. If PIM was run in dynamic mode, then the user must select any one of the *pim_pud.out* files with a time extension.

RAYTRACE-APP Outputs

The RAYTRACE application outputs a 1D Gridded Data set of ray traces plus a slice of the PIM electron densities approximately in the plane of the traced rays. These outputs are displayed using the RAYTRACE graphical object. If a dynamic PIM run was performed and the file extension option was selected when running PIM, then the RAYTRACE-APP output will also be dynamic with one set of traced rays for each PIM time frame.

Plot Options: The *Plot Options* button activates a Ray Plot Options popup window used to tailor the appearance of the special 1D plot activated by the *Display Plot* button (see below). The display options include:

Range: The *Range* text box set controls the minimum (*Min*) and maximum (*Max*) values to be plotted as well as the number of tic marks (*Tic*) along the horizontal axis representing range in km.

Alt: The *Alt* text box set controls the minimum (*Min*) and maximum (*Max*) values to be plotted as well as the number of tic marks (*Tic*) along the vertical axis representing altitude in Km.

Defaults: The *Defaults* buttons reset the *Range* and *Alt* text box values back to their default settings. The default minimum range and altitude is 0 km. The default maximum range is 12000 km. The default maximum altitude is 600 km.

Auto: The *Auto* buttons set the *Min/Max* values of *Range* and *Alt* such that all of the data fits in the special 1D plot window.

Captions: Selecting this option displays color coded captions of the form "F #.# E #.#" for each ray traced, e.g., a caption "F15.0 E20.0" indicates that the ray trace of the same color as the caption was determined using a frequency of 15 MHz and was emitted at an elevation angle of 20 degrees. Only the first six rays are color coded, the rest are white. No captions appear for white ray traces. The *Caption X* and *Caption Y* sliders are used to position the caption text within the special 1D plot.

Plasma Frequency: Selecting this option displays an isocontour of the plasma frequency selected using the adjacent slider. The slider is labeled with the relative frequency (0.0-1.0), the frequency in MHz, and the equivalent plasma density in #/cm^3.

OK: The OK button dismisses the Ray Plot Options popup window.

Display Plot: The *Display Plot* button produces a special 1D viewport displaying the ray traces as a function of altitude and range from the transmitting location. The *Plot Options* button (see above) can be used to add color-coded captions providing frequency (F) and elevation (E) information for each ray trace as well as plasma frequency contours.

Note: In dynamic mode, the 1-D special window animates only if a 3-D window containing the corresponding RAY TRACE graphical object is currently displayed.

The SATEL-APP Module

Model Name:	LOKANGL and SPACETRK (SGP4)
Version:	LOKANGL: 18 August 1997 SPACETRK (SGP4): 15 August 1997
Developer:	LOKANGL: Radex, Inc. (now AER, Inc.) SPACETRK (SGP4): Air Force Institute of Technology (modified by Radex, Inc. (now AER, Inc.))
References:	Bass, J.N., K.H. Bhavnani, B-Z.J. Guz, R.R. Hayes, P.N. Houle, S.T. Lai, and L.A. Whelan, Analysis and Programming for Research in Physics of the Upper Atmosphere, *AFGL-TR-76-0231*, p. 56-71 (1976) (LOKANGL), ADA 034066 Kerns, K.J., and M.S. Gussenhoven, CRRESRAD Documentation, *PL-TR-92-2201*, Phillips Laboratory, Hanscom AFB, MA (1992) (LOKANGL), ADA 256673

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

SATEL Overview

The SATEL application module provides an interface to the LOKANGL and SGP4 orbit generation and prediction codes. The interface and code generation are shared among several modules requiring code orbit ephemerides. Other modules using the orbit generation module are the BFOOTPRINT, CRRESRAD, CRRESPRO, CRRESELE, NASAELE, NASAPRO, LET, and TPM applications.

SATEL Inputs

Input to the SATEL application comprises orbital elements, start and stop times of the orbit interval to be predicted, and parameters defining detector and link options. Several methods for inputting the orbital elements are available.

The input window is logically divided into three areas: a propagator/element type section, an orbital element input section, and an auxiliary input area. The paragraphs below will describe the inputs requested by each of the three logical input areas.

Propagator/Element Type Specification

The SATEL application allows the orbit to be generated by using either the LOKANGLE or SGP4 orbit propagator codes. In addition, the orbital elements to be used by the propagator may be specified in a variety of ways.

The *Propagator* input section allows the user to specify which of the following propagators to use in calculating the orbit,

Lokangle:	Lokangle, an orbit prediction code developed by Radex, Inc. (now AER, Inc.) (see notes below).

SGP4: The SGP4 portion of the SPACETRK code developed by the Air Force Institute of Technology.

The *Element Type* input section allows the user to specify how the orbital elements will be input. The choices are

Mean Elements: The Mean orbital elements will be specified. When this selection is chosen, the orbital element input section will display text boxes and labels for input of Inclination, Arg. of Perigee, Mean Anomaly, Eccentricity, Right Ascension of Ascending Node and Mean Motion of the satellite. See *Mean Elements Inputs* below for more information. **Note**: When the *From File* option is selected, the elements read from file will appear in the Mean Element text boxes.

P/V (ECI): The Position/Velocity orbital elements will be specified. When this selection is chosen, the orbital element input section will display text boxes and labels for input of three position components and three velocity components. See *P/V (ECI) Inputs* below for more information.

Solar: The Solar orbital elements will be specified. When this selection is chosen, the orbital element input section will display text boxes and labels for input of Inclination, Apogee, Perigee, and local time of Apogee and maximum latitude. See *Solar Inputs* below for more information. If the Perigee altitude is less than the Apogee value entered then an error popup window appears and a message is written to standard output.

SMean: The Simple Mean orbital elements will be specified. When this selection is chosen, the orbital elements input section will display text boxes and labels for input of Inclination, Right Ascension of Ascending Node, Argument of Perigee, Apogee Altitude, and Perigee Altitude (Mean Anomaly is fixed equal to zero). See *SMean Inputs* below for more information. If the Perigee altitude is less than the Apogee value entered then an error popup window appears and a message is written to standard output.

From File: It is common to store orbital elements in files of two-line NORAD orbital elements. The *From File* option allows a user to choose a file containing a series of two-line NORAD elements. When this option is chosen, the orbital element input section will display a list of satellite names corresponding to the element sets read from the specified file. See *Select From File* below for more information on this choice, the format of the NORAD element set file, and how to obtain a file of orbital elements. **Note**: When the *From File* option is selected, the elements read from file will appear in the *Mean Element* text boxes.

Note: Lokangle supports all of the provided *Element Type* options. SGP4 supports all *Element Type* options except the position-velocity element option *P/V (ECI)*.

Element Input Section

One of five sets of text fields will appear depending on the orbital *Element Type* selected,

(1) Mean Elements Inputs,

Inclination: The inclination of the satellite orbit specified in degrees.

Arg. of Perigee: The argument of the perigee of the satellite orbit measured in degrees.

Mean anomaly: The mean anomaly of the satellite orbit specified in degrees.

Eccentricity: The eccentricity of the satellite orbit.

R. A. Asc. Node: The right ascension of the ascending node of the satellite orbit specified in degrees.

Mean Motion: The mean motion of the satellite specified in rev/day.

d(MM)/dt/2: One-half the first time-derivative of the mean motion of the satellite is specified in rev/day^2.

d2(MM)/dt2/6: One-sixth the second time-derivative of the mean motion of the satellite is specified in rev/day^3.

BSTAR: The SGP4-type drag term (units of Re^{-1}), the ballistic coefficient represents how susceptible an object is to drag with a value of zero representing no drag.

Note: The original PC-based versions of the CRRESELE, CRRESRAD and CRRESPRO applications do not use the mean motion time derivatives in the orbit calculations. Although the differences should be small, if precisely matching the original PC-based results is important to the user, d(MM)/dt and d2(MM)/dt2 should be set to zero when running the BFOOTPRINT, CRRESELE, CRRESRAD, CRRESPRO, NASAELE, NASAPRO, LET, and TPM applications.

(2) P/V (ECI) Input unit type is controlled by the *km* and *ft* option switches below the velocity text boxes. With the *km* option selected, position and velocity values are entered in units of km and km/sec, respectively. With the *ft* option selected, position and velocity values are entered in units of ft and ft/sec, respectively. After entering the text field, switching between the *km* and *ft* options will translate the position and velocity values automatically to the other set of units.

Px, Py, Pz: The X, Y, and Z position of the satellite specified in km. The coordinate system is Earth Centered Inertial (X = first point of Ares, Y = X x Z, Z = north rotational pole).

Vx, Vy, Vz: The Vx, Vy, and Vz velocity components of the satellite specified in km/s. The coordinate system is Earth Centered Inertial (X = first point of Ares, Y = X × Z, Z = north rotational pole).

P. Decay: The period decay of the satellite orbit, specified in s/rev.

Note: The PC-based versions of the CRRESELE, CRRESRAD and CRRESPRO applications do not use the period decay in the orbit calculations. Although the differences should be small, if precisely matching the PC-based results is important then *P. Decay* should be set to zero when running the BFOOTPRINT,

CRRESELE, CRRESRAD, CRRESPRO, NASAELE, NASAPRO, LET, and TPM applications.

(3) Solar Inputs,

Inclination:	The inclination of the satellite orbit specified in degrees.
Apogee (km):	The altitude of the satellite orbit apogee specified in kilometers.
LT of Max Lat:	The local time of maximum latitude (inclination) specified in hours.
Perigee (km):	The altitude of the satellite orbit perigee specified in kilometers.
LT of Apogee:	The local time of apogee specified in hours.

(4) SMean Inputs,

Inclination (deg):	The inclination of the satellite orbit specified in degrees.
RAA Node (deg):	The right ascension of the ascending node of the orbit specified in degrees.
Perigee Arg (deg):	The argument of the perigee of the satellite orbit measured in degrees.
Apogee Alt (km):	The altitude of the satellite orbit apogee specified in kilometers.
Perigee Alt (km):	The altitude of the satellite orbit perigee specified in kilometers.

(5) Select From File,

Files containing sets of NORAD two-line element sets are commonly available. The *From File* input option provides a means of reading files containing element sets and using them to generate orbits in AF-GEOSpace. When the *From File* button is activated the Ephemeris Data window displays a label showing the currently opened file, a *Select File* button to open a file selection box to change the current file, and a list of elements parsed from the current file. When the *Sort* button (next to the *Select File* button) is checked, the next execution of *Select File* returns an alphabetically sorted list of elements parsed

After a file is opened the user can click the desired label in the element selection box to choose the orbit elements associated with the named satellite. When this is done, the elements for the chosen orbit are loaded and will appear in the text boxes associated with the Mean element type.

In order to correctly parse the element sets, AF-GEOSpace expects the chosen file to contain elements in a specific format. Information on the supported NORAD two-line element format is available from Celestrak.com via anonymous ftp (see below). A copy of this document may also be found in $AFGS_HOME\models\data\EPHEMERIS\NORAD_Two.doc.

Standard installations of AF-GEOSpace Version 2.5.1 set the default start-up element file as $AFGS_HOME\models\data\EPHEMERIS\tle.new.

Files containing ephemeris data for a large number of current and historic satellites are available from *http://Celestrak.com*. A broad array of satellite orbit classes are represented at this site with ephemeris for each type typically stored in a different text file, e.g., the file goes.txt contains GOES satellite two-line element sets. To download the current goes.txt file, for example, go to the *Current Data* section of the website, right-click on *GOES* and choose “Save Link As”, and place the file in the $AFGS_HOME\models\data\EPHEMERIS.

Note that ephemeris files received from Celestrak.com representing multiple satellites are typically written using the 3-line format that the AF-GEOSpace software expects to handle. These files contain the name of the spacecraft on the first line and the element set on the next two lines, e.g.,

```
NOAA 9
1 15427U 84123A   06191.17285276 -.00000060  00000-0 -93142-5 0  3437
2 15427  98.4952 228.3827 0013953 269.2867  90.6712 14.15238022113188
NOAA 10
1 16969U 86073A   06191.20809939  .00000079  00000-0  50616-4 0  2713
2 16969  98.7581 202.8899 0013370  83.8117 276.4588 14.27298964 30444
NOAA 11
1 19531U 88089A   06191.20315288 -.00000028  00000-0  85243-5 0  1910
2 19531  98.8270 279.3724 0010851 285.5674  74.4282 14.14811788917794
```

Archive files representing orbit elements over time for a single spacecraft from Celestrak.com typically do not include the first line with the spacecraft name, so the user must manually insert the name if AF-GEOSpace is expected to process it properly. The simplest way to accomplish this is to use standard word processing software and perform a universal "replace", e.g., the following 6 lines in a single text file might represent three sets of two-line elements for the CHAMP spacecraft.

```
1 26405U 00039B   02010.72651584 +.00020203 +00000-0 +33586-3 0 0496
2 26405 087.2608 305.3408 0032340 002.8614 357.2836 15.5131749208398
1 26405U 00039B   02011.75860482 +.00023132 +00000-0 +38401-3 0 0497
2 26405 087.2615 304.9473 0032032 358.5732 001.5494 15.5136860408414
1 26405U 00039B   02012.66165175 +.00026059 +00000-0 +43202-3 0 0500
2 26405 087.2614 304.6013 0031672 354.9710 005.1235 15.5141864208428
```

If the character string

"`1 26405U`"

is universally replaced by a line with the spacecraft name (plus a line return) and the characters used to locate the naming text, e.g.,

"`CHAMP`" (with a line return)
"`1 26405U`"

then the file will be properly formatted for AF-GEOSpace use and appear as follows.

```
CHAMP
1 26405U 00039B   02010.72651584 +.00020203 +00000-0 +33586-3 0 0496
2 26405 087.2608 305.3408 0032340 002.8614 357.2836 15.5131749208398
CHAMP
1 26405U 00039B   02011.75860482 +.00023132 +00000-0 +38401-3 0 0497
2 26405 087.2615 304.9473 0032032 358.5732 001.5494 15.5136860408414
CHAMP
1 26405U 00039B   02012.66165175 +.00026059 +00000-0 +43202-3 0 0500
2 26405 087.2614 304.6013 0031672 354.9710 005.1235 15.5141864208428
```

Auxiliary Input Section

The auxiliary input area is used to specify information such as the reference time of the satellite orbit elements and the time period for which the orbit should be calculated. The information is either input by the user or loaded from the satellite ephemeris files when the *From File* option is used. Specifically, the inputs are:

T_ref:	The reference time of the orbital elements of the satellite, specified in the form DD/MM/YY HH:MM:SS.SSS
T_start, T_stop:	The start and stop time for which the orbit is to be calculated, specified in the form DD/MM/YY HH:MM:SS.SSS. Note that *T_start* and *T_stop* must be greater than *T_ref* (strictly enforced when using SGP4 propagator). Note that if the *SGP4* propagator is used, the orbit interval must be within a year of *T_ref* or the application will issue an error warning. In static mode, the default *T_stop* value is 24 hours after *T_start*. In dynamic mode, the *T_start* and *T_stop* times match the Start and End times entered at the top of the environment window.
Time Step:	The time step interval used to calculate the orbit is specified in seconds. The orbit calculation will go from *T_start* to *T_stop* in *Time Step* increments.
Sat. Name:	A mnemonic for the satellite useful for display purposes.
Time Step:	The time step, in seconds, at which the orbit should be calculated.

SATEL Outputs

The SATEL application outputs a 1D Gridded Data Set of the position of the selected satellite as a function of time. The output can be viewed using the SATELLITE graphics module.

The TPM-1-APP Module (V2.5.1 Only)

Model Name:	Trapped Proton Model (TPM-1)
Version:	Version 1.2, 15 April 2003; IGRF updates 2009
Developer:	S. L. Huston, The Boeing Company
References:	Huston, S.L., Space Environment and Effects: Trapped Proton Model, *NASA/CR-2002-211784*, NASA Marshall Spaceflight Center (2002) [see $AFGS_HOME\models\REFS\TPM.pdf]
	Huston, S.L., and K.A. Pfitzer, Space Environment Effects: Low Altitude Trapped Proton Model, *NASA/CR-1998-208593*, NASA Marshall Spaceflight Center (1998)
	Huston, S.L, G.A. Kuck, and K.A. Pfitzer, Low altitude trapped radiation model using TIROS/NOAA data, in *Radiation Belts: Models and Standards*, J.F. Lemaire, D. Heynderickx, and D.N. Baker (eds.), *Geophysical Monograph 97*, American Geophysical Union, 119 (1996)
	Meffert, J.D., and M.S. Gussenhoven, CRRESPRO Documentation, *PL-TR-94-2218*, Phillips Laboratory, Hanscom AFB, MA (1994), ADA 284578
	Olson, W.P., and K.A. Pfitzer, Magnetospheric Magnetic Field Modeling, Annual Scientific Report, Air Force Office of Scientific Research contract F44620-75-C-0033, McDonnell Douglas Astronautics Co., Huntington Beach, CA (1977), ADA 037492

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

TPM-1-APP Overview

The TPM-1 science and application modules are based on the Trapped Proton Model (TPM) developed by Boeing Corporation for the NASA Space Environment and Effects (SEE) Program [*Huston,* 2002]. TPM combines both the Low Altitude Trapped Radiation Model (LATRM) [*Huston et al.,* 1998], also developed by Boeing for NASA/SEE, and the Air Force Research Laboratory's (AFRL) CRRESPRO model [*Meffert and Gussenhoven,* 1994] covering higher altitudes. More information on TPM-1 can be found in the TPM-1 Science Module section of this document.

The CRRESPRO-APP module calculates proton omni-directional fluence (differential and integral) over the energy range 1-100 MeV for user specified orbits and quiet or active geophysical conditions. For this application, the TPM-1 data base is accessed and copied to a local (time dependent) set of data files in CRRESPRO format. The calculation of fluences then proceeds in the same manner as in CRRESPRO-APP.

Integral omni-directional fluence for a given energy channel is calculated from the differential omni-directional fluence by summing over all energy channels with energy greater than the given channel (eliminating those with overlapping energy ranges, channels 5 and 15) and multiplying by appropriate bandwidths, as discussed in the CRRESPRO Science Module.

Note: The TPM-1 Science Module need NOT be run before TPM-1-APP.

TPM-1-APP Inputs

The inputs to the TPM-1-APP module are the orbit elements needed to calculate the satellite orbit. The Environment Window for the TPM-1-APP module is the same as that for the SATEL-APP application except TPM-1-APP is set to use the orbit propagator Lokangle. See the SATEL-APP Module section of the documentation for input descriptions. The IGRF/O-P magnetic field model is used with extrapolation beyond 2010.

TPM-1-APP Outputs

The TPM-APP Applications Module generates a return text window which can be displayed using the *Show Text* button if it has been closed. Included in the text are the orbit elements and tables of both the differential and integral omni-directional fluences (in units of #/(cm^2 MeV yr) and #/(cm^2 yr), respectively) calculated for all 22 retained energy channels and for both active and quiet conditions. Also generated is a 1D Gridded Data Set giving the position of the satellite as a function of time that can be displayed using the Satellite Graphics Module.

The WBPROD-APP Module (V2.5.1 and Static Only)

Model Name:	Wide-Band Model (WBMOD)
Version:	September 1998 (Uses WBMOD Version 15.03 of 08 July 2005)
Developer:	USAF 55SWXS, Air Force Research Laboratory, and Radex, Inc. (now AER, Inc.)
References:	Secan, J.A., and R.M. Bussey, An Improved Model of High-Latitude F-Region Scintillation (WBMOD Version 13.04), *PL-TR-94-2254* (1994), ADA 288558

Note: It is recommended that AF-GEOSpace users read the original model documentation and descriptive articles before using the models.

WBPROD-APP Overview

The WBPROD-APP application produces a 24-hour forecast of the 95th percentile dB fade levels along user-specified communication link(s) between a receiver site and satellites. The WBMOD climatological ionospheric scintillation model is used and is described in more detail in the WBMOD Science Module section of this User's Manual. In the science module, WBMOD is executed in a transmitter- or receiver-step mode at a fixed time. This application executes WBMOD in a time-step mode with the communication link(s) fixed in location. WBPROD-APP outputs a summary text file of the hourly 95th percentile fades for a specified day of year and ground-to-satellite link. Multiple satellite links to a single ground point can be written to the same file. An option also exists to output a text file with the set of WBMOD parameters for the specified link.

Note: WBPROD-APP does not produce gridded output data for viewing with the AF-GEOSpace graphics modules. This module is a tailored product designed to run WBMOD scripts quickly and efficiently. This is an excellent tool for generating scintillation products required for routine customers.

WBPROD-APP Inputs

The following *Run Variables* are mandatory,

Note: This application DOES NOT use the AF-GEOSpace global parameters at the top of the Environment Window, but uses those entered in the following text fields.

Day#:	The day of the year, e.g., 1 = 1 Jan and 365 = 31 Dec (for non-leap year).
Kp:	The average geomagnetic Kp index forecast for the day.
SSN:	The sunspot number forecast for the day.

The following *Station* variables are required to specify the ground station location,

Name:	Name of the ground station. If you saved a previous session and wish to re-load it, type in the name of the ground station (exactly as named before) and click on the *Load Script* button (see related discussion below).
Lat (deg N):	The geographic latitude of the ground station in degrees North.

Lon (deg E): The geographic longitude of the ground station in degrees East.

Alt (km): The altitude of the ground station above sea level in kilometers.

The following *Satellite* variables are required to specify the locations and communication frequencies for the satellites,

Name: The satellite name (must be unique).

Lat (deg N): The geographic latitude of the satellite in degrees North. Remember, this application steps WBMOD in time, the satellite link will be fixed in position.

Lon (deg E): The geographic longitude of the satellite in degrees East. Remember, this application steps WBMOD in time, the satellite link will be fixed in position.

Alt (km): The satellite altitude above the center of the Earth in kilometers. Note that station altitude is specified using a different zero point. Because the current version of WBMOD does not include doppler effects due to satellite velocity, it is recommended that only geosynchronous satellite positions are inputted (Alt ~ 36,000 km).

Freq (MHz): The carrier frequency of the communications signal in MHz.

Once the satellite variables have been input, the satellite must be added to the active satellite list displayed at the bottom of the window by clicking on the *Add/Update* button. Additional satellites can then be entered in the variable boxes and added to the list in a similar fashion. Satellites can be deleted from the list by first clicking on the satellite name in the active satellite list and then clicking on the *Delete* button. WBPROD-APP will produce forecasts for all the satellites in the active satellite list.

Before running WBPROD-APP, the *Save Script* button **must be clicked**. This will save the station and satellite parameters in a file labeled *stationname.wb*, where *stationname* is the Name entered for the station in the current window.

The *Load Script* button resets inputs from the last Save Script action and not from a previous session. Use the *Save Model* option from the *File* menu to save session details for future use. The file entitled *stationname.wb*, where *stationname* is the *Name* entered for the station in the current window will be loaded into WBPROD-APP.

The user can choose to have either a *Summary* output (SI index only) or *All* the WBMOD output parameters saved to a file by selecting the appropriate *Text* option before execution.

Note: The *Save Script* button must be clicked before executing WBPROD-APP or else the last saved script will be run.

WBPROD-APP Outputs

Use the *Display Text* button to display output in an AF-GEOSpace text window. The following options are available.

Summary: Creates an ASCII text file labeled *stationname_summary*, where *stationname* is the *Name* entered for the station in the current session. This

file lists the hourly values of the 95th percentile fades for links from the ground station to all the satellites in the active satellite list. Fades are reported as negative values (dB).

All: Creates an ASCII text file labeled *stationname_all*, where *stationname* is the *Name* entered for the station in the current session. This file lists the hourly values of all the WBMOD output parameters including S4, sigma phi, 95th percentile fade, STDEV LOG(I), and %Time for links from the ground station to all the satellites in the active satellite list. See the *WBMOD Science Module* section of this User's Manual for further details.

GRAPHICS MODULES

Graphics modules are used to visualize the data sets created with the Application, Data, and Science modules. The inputs to a graphics module are 1D, 2D, 3D, Spectral, or Heliospace Data Sets and the outputs are defined as graphical objects. A variety of graphics modules are provided for one-, two-, and three-dimensional visualization. The graphics modules are accessed through the graphics manager that becomes visible when the *Graphics* option in the *Module* pulldown menu is activated. The graphics manager consists of two lists - *Available Modules* and *Active Modules*. *Available Modules* are the modules that are currently supported by AF-GEOSpace. *Active Modules* are modules that have been created and used by the AF-GEOSpace user during the current session.

When initially accessed, the graphics manager will show a list of graphics under *Available Modules* and the *Active Modules* list will be empty.

Currently, the following graphics are supported by AF-GEOSpace:

- **ANNOTATION:** Create and display descriptive text or time labels for viewports.
- **AXES:** Plot a set of axes or the sun vector.
- **COORD-PROBE:** Provides a method for probing data along lines defined in user-specified coordinate systems.
- **COORD-SLICE:** Display a slice of a data set along a constant coordinate surface.
- **DETECTOR:** Define and associate fixed or tracking detector cones with satellites or station locations.
- **DMSP**: Display DMSP precipitating particle data (processed using the DMSP Data Module) in 1D and Spectral windows.
- **EARTH:** Plot an outlined or solid Earth. A variety of outline detail and grid options are available.
- **EMITTER:** Define and associate fixed or tracking emitters, e.g., radar fan structures, with satellites or stations.
- **FIELD-LINES:** Plot magnetic field lines, flux tubes, and auroral equatorward boundaries.
- **GLOBAL INPUTS:** Produce a line plot of the global input data values, e.g., Kp or Dst, as a function of time.
- **GRID**: Plot the grid associated with a data set.
- **IONSCINT-G:** Display platform-based GPS frequency S4 scintillation simulation results (generated using the IONSCINT-G Science Module) in 1-D and Spectral windows.
- **ISOCONTOUR**: Calculate an isocontour of a data set and plot the resulting surface.
- **LINK:** View a line-of-sight link between stations and satellites or between satellites.
- **ORBIT-PROBE:** Plot data sets from along satellite orbits.
- **ORBIT-SLICE:** Cut the data set with a plane placed at the orbital plane of a satellite (or a plane perpendicular to or containing the satellite velocity vector) and plot the resulting slice.

- **PLANE-SLICE:** Cut the data set with an arbitrary plane and plot the resulting slice.
- **RAY TRACE:** Produce a depiction of the ionospheric rays traced through the PIM science model data sets.
- **SATELLITE:** Provides a means of viewing satellite trajectories, detector cones, and communications links.
- **STARS:** Plot the celestial background including stars, planets, and the moon.
- **STATION:** Plot a labeled location on or above the surface of the Earth.
- **VOLUME:** View the entire volume of a data set as a single three-dimensional object
- **PARAMESH-COORDSLICE:** Produce a slice or constant coordinate surface through a PARAMESH data set.
- **PARAMESH-FIELDLINES:** Produce field lines generated by tracing a vector field through a PARAMESH data set.
- **PARAMESH-FIELDLINES II:** Produce field lines generated by tracing a vector field through a PARAMESH data set.
- **PARAMESH-GRID:** Display the grid, block structure (e.g., leaf and parent block), and overall domain of a PARAMESH data set.
- **PARAMESH-ISOCONTOUR:** Produce a surface of constant value through a three-dimensional PARAMESH data set.
- **PARAMESH-VOLUME:** View the entire volume of a PARAMESH data set as a single three-dimensional object.

Running Graphics Modules

To run a graphics module, use the mouse to select the *Graphics* option in the *Module* pulldown menu and *Available Modules* and *Active Modules* lists will appear in the Environment Window. Click on the desired choice under *Available Modules*. For example, to create a new COORD SLICE, click the mouse on *Coord Slice* in the *Available Modules* list. Choosing a graphics module will do two things: first, the choice is added to the *Active Modules* list; second, the options associated with the chosen graphics module will appear in the Environment Window. In general, each graphics module will have a different Environment Window representing the module specific inputs. Before attempting to display a graphics object, adjust the settings and/or select an existing data set from the options presented in the Environment Window.

The *Display* selector places the graphical object in the active viewport window. Note that this selector is only active when the dimensionality of the data is appropriate for the current active window, e.g., 3D data cannot be displayed in a 1D viewport. If required, use one of the *Create Viewport* options in the *Window* pulldown menu to create a window of appropriate dimensionality or use the *Projection* option in the *Viewport* pulldown menu to change the dimensionality of the active viewport window.

Alternating the *Projection* option in the *Viewport* pulldown menu between *Two D* and *Three D* is one way to view the same data in both dimensions. An even easier method is to use the *Split* option in the *Viewport* pulldown menu to divide a 2D (3D) viewport and then change the dimensionality of one of the viewports to 3D (2D).

The *Interactive* selector (usually active by default) controls whether graphical renderings are updated as changes are made to the graphic inputs.

The *Use Texture* selector (usually active by default) option improves the appearance of color data contours and its use is recommended.

The appearance of the graphical object also be modified using the *Lighting*, *Clipping*, *Transparency*, *Lights*, *Material*, *Color*, *Color Map*, and *Data Map* options also available in the Environment Window. See the Graphical Module Options section of this manual for details of these features.

The *Animate Tool* option in the *Edit* pulldown menu can be used to display data produced in dynamic mode, i.e., if a science or application module was run using a *Start* and *End* time. SATEL-APP module output, i.e., satellite orbits, can be animated using this tool even if when run in static mode because the satellite module permits setting

The *Delete* option in the *Edit* pulldown menu is used to remove the highlighted science module member of the *Active Modules* list. Note that all active graphics objects must be removed before the science module used to generate their data can be removed.

ANNOTATION

The ANNOTATION graphical object is used to display fixed text messages or the time and date in the graphics windows.

The ANNOTATION graphical object rendering is dependent on the window type.

In a 1D window, the ANNOTATION graphical object displays text in the graphics window.

In a 2D window, the ANNOTATION graphical object displays text in the graphics window.

In a 3D window, the ANNOTATION graphical object displays text in the graphics window.

In a HelioSpace window, the ANNOTATION graphical object displays text in the graphics window.

In a Spectral window, ANNOTATION does nothing.

The ANNOTATION graphical object supports the *Color* option.

ANNOTATION Inputs

Text: The *Text* field can be edited to contain the text to be displayed in the graphics window. The text will not appear while the Show Data option is activated.

Show Date: This option displays the time and date in place of the contents of the *Text* field.

Font: The *Font* selector controls the font size used for the annotation. The options include the machines *Default* font (size 20) and Times font (sizes *10, 20, 30, 40,* and *50*).

X Position: The *X Position* slider is used to position the annotation in the horizontal direction.

Y Position: The *Y Position* slider is used to position the annotation in the vertical direction.

AXES

The AXES graphical object will produce a set of AXES for different coordinate systems. It will also produce a vector representing the sun direction, given the current time as set by the UT Global parameter or the Animation Window.

The AXES graphical object rendering is dependent on the window type.

In a 1D window, the AXES graphical object does nothing.

In a 2D window, the AXES graphical object does nothing.

In a 3D window, the AXES graphical object plots lines representing X, Y, and Z axes with the origin at the center of the Earth.

In a Heliospace window, AXES does nothing.

In a Spectral window, AXES does nothing.

The AXES graphical object supports the *Color* option.

AXES Inputs

Axes Frame: The coordinate system in which the axes should be aligned. Assigned axis colors can be changed using the *Color* display option. Choices are:

- GEOC: Geocentric coordinate system axes: The Z axis (blue) is aligned with the north rotational pole, the X axis (red) pierces the Greenwich Meridian on the equator (0 deg Long, 0 deg Lat), and the Y axis (green) is equal to the negative of the cross-product of X and Z.
- GEI: Geocentric equatorial inertial coordinate system axes: The Z axis (blue) is the same as for the *GEOC* coordinate system. The X axis (red) is aligned along the vernal equinox. The angle between the vernal equinox and the Greenwich Meridian is set using the current UT from the Animation Window.
- GSM: Geocentric solar magnetospheric coordinate system axes: The X axis (red) points to the Sun. The Z axis (blue) is perpendicular to X and lies in the plane containing the magnetic dipole axis. The Y axis (green) completes the right-handed system and is positive towards dusk.
- SM: Solar magnetic coordinate system axes: The X axis (red) is perpendicular to Z and lies in the plane containing the Z axis and the Earth-Sun line. The Z axis (blue) is coincident with the magnetic dipole axis. The Y axis (green) completes the right-handed system and is positive towards dusk.

Sun vector: Solar direction axis: The direction of the sun (yellow) is based on the current UT from the Animation Window.

Axes Specification: This section controls the display of the axes. The options are:

Show Axes: For each of the axis components, activating the *Show Axes* toggle button makes the axis visible.

Show Tics: For each of the axis components, activating the *Show Tics* toggle button makes the tick marks on the axis visible.

Major Tic Spacing: The spacing (in Re) between major tick marks.

Minor Tic Spacing: The spacing (in Re) between minor tick marks.

Axes Length: The *Axis Length* slider controls the length of the axis to be drawn. Units are Earth radii (Re).

COORD-PROBE

The COORD-PROBE graphical object is used to produce a line plot through a data set. The line variable may be specified along a given coordinate direction in one of several coordinate systems.

The COORD-PROBE graphical object rendering is dependent on the window type.

In a 1D window, the COORD-PROBE graphical object produces a line plot of data values colored according to the parameter value.

In a 2D window, COORD-PROBE will project the line through the data set onto a 2D grid of longitude (horizontal) and latitude (vertical). Note: Use the Earth grid to frame the plot.

In a 3D window, COORD-PROBE will display the line through the data set in three-dimensional space around the Earth.

In a Heliospace window, COORD-PROBE does nothing.

In a Spectral window, COORD-PROBE does nothing.

The COORD-PROBE graphical object supports the *Color* and *Data Map* options.

COORD-PROBE Inputs

Data:	This option menu is used to select the main data set the COORD-PROBE is to be taken through. This option must be set before rendering is allowed. The option menu contains a list of valid, previously run science, data, and application data sets.
System:	The coordinate system in which the coordinate line will be generated. The user may select to probe the data set in geocentric (*GEOC*), geocentric solar magnetospheric (*GSM*), solar magnetic (*SM*), or geocentric equatorial inertial (*GEI*) coordinates.
Geometry:	Specify the geometry in which the coordinate line will be generated. The user may select *Cartesian*, *Cylindrical*, or *Spherical* geometry.
Vary:	Specify the coordinate along which the probe is to vary. These options will change depending on the settings of the *Data*, *System*, and *Geometry* inputs. In the cylindrical geometry, for example, the *Vary* selections will read *Radius*, *Phi*, and *Z*. The two sliders below the *Vary* options control the values of the two fixed coordinates.
Steps:	The number of points along the coordinate variable at which the data set is to be sampled.
Type:	The *Type* options are used to select how the linear data are plotted, i.e., as discrete points (*Point*), a solid line (*Line*), or stippled line (*Stipple 1* and *Stipple 2*).
Thickness:	The *Thickness* slider controls the width of plotted points and lines.
X Axis:	Displayed *X Axis* features are controlled by the following options:

Enabled:	The *Enabled* check box controls the display of axis labels.
Grid:	The *Grid* check box places grid lines at axis tic mark locations.
Min, Max:	The *Min* and *Max* text boxes are used to control the range of values plotted. After editing either value, the plot will update when the cursor is placed in any one of the other text boxes in the environment window.
Auto:	The *Auto* button adjacent to the *Min* and *Max* text boxes automatically resets the plot range to the minimum and maximum values of the data set.
Format:	The *Format* text box determines the format of the tic mark labels. "C"-like format statements are accepted, e.g., "%5.2f" will label the tics using floating point numbers with two decimal places. Substitute an "e" for "f" and exponential formatting will be used. After editing a *Format* text box, the display will update when the cursor is placed in any other text box in the environment window.
Num Tics:	The *Num Tics* text box controls the number of labels and tic marks along the axis. Update by placing the cursor in another text box.

Y-Axis: The *Y Axis* options are the same as the *X Axis* options described above with the following additional capabilities:

Side:Left, Right:	The *Left* and *Right* buttons determine the display side of the axis labels.
Log:	The *Log* check box activates the use of a log base 10 scale. When applied to number values less than or equal to zero, the *Log* function will display a "-6" on the log scale.

Save: The *Save* button activates a *Save As* popup window used to save the 1-D displayed data to a text file. Designated file names should end with ".txt" for viewing convenience.

COORD-SLICE

The COORD-SLICE graphical object is used to produce a slice or surface through a data set. The slice is produced along a constant of one coordinate direction. For example, if the data set was produced on a spherical grid, the COORD-SLICE graphical object can produce slices at constant radius, constant latitude, or constant longitude. If the data set was produced using a Cartesian grid, the COORD SLICE graphical object could produce a slice at constant X, Y, or Z value.

The COORD-SLICE graphical object rendering is dependent on the window type.

In a 1D window, the COORD-SLICE graphical object does nothing.

In a 2D window, COORD-SLICE will project the constant coordinate slice onto the Earth's surface. Note that for this to be meaningful, the slice should be produced at constant altitude on a spherical grid, i.e., use *Cut Plan C0*.

In a 3D window, COORD-SLICE will display the coordinate slice through the data set in three-dimensional space around the Earth.

In a Heliospace window, COORD-PROBE does nothing.

In a Spectral window, COORD-PROBE does nothing.

The COORD-SLICE graphical object supports the *Clipping*, *Transparency, Lights, Material, Color, Color Map*, and *Data Map* options.

COORD-SLICE Inputs

Data: The *Data* option menu is used to select the main data set the COORD-SLICE is to be taken through. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously run science, data, and application data sets.

Block Rendering: The *Block Rendering* option displays the data using single-colored blocks centered on grid points which are colored according to the their data value.

Cut Plane: The *Cut Plane* option defines the constant coordinate from the choices *C0*, *C1,* and *C2*. The generic names represent specific coordinate choices depending upon the grid type of the data set. For example, if the grid type of the data set is spherical, *C0* will produce a slice at constant radius; *C1* will produce a slice at constant latitude; *C2* will produce a slice at constant longitude. Similarly, if the data set has a Cartesian grid, the *C0*, *C1*, and *C2* will produce slices at constant X, Y, and Z, respectively.

Display Options: The *Display Options* field will allow the COORD-SLICE to be filled as colored or white contours, filled or discrete. Any combination of the options may be selected.

Filled: Render the COORD-SLICE as solid, filled, color contours.

Grey: If the grid extends beyond meaningful data in the data set, the points without valid data will be filled in as grey.

Contours: Render the COORD-SLICE as discrete white lines. The lines represent isovalues of the data evenly spaced between the data minimum and the data maximum. The number of contours is determined by the *Number of Contours* input.

Color: The isovalue lines are colored according to the color bar to represent the magnitude of the isovalue.

Grid: An outline of the grid will be shown in the plane of the coordinate slice.

Position Value: The *Position Value* option determines the position of the coordinate slice. The position value represents the position along the constant coordinate. For example, if the dataset has a spherical grid and the *C0* coordinate is chosen, COORD-SLICE will produce a slice at constant radius. The position value input will select the value of the radius at which to produce the slice. The value will range from the grid minimum to the grid maximum for the chosen coordinate.

Number of Contours: The *Number of Contours* input slider determines the number of contour lines to be plotted between the data minimum and the data maximum if the *Display Option* selection is just *Contours* or *Contours: Color* (see above).

DETECTOR

The DETECTOR graphical object is used to view a detector located at a station or in orbit on a satellite. The stations and satellites to be associated with a detector must have been displayed previously using the STATION graphics module and the SATEL-APP and SATELLITE modules, respectively.

The DETECTOR graphical object rendering is dependent on the window type.

In a 1D window, the DETECTOR graphical object does nothing.

In a 2D window, the DETECTOR graphical object displays the detector cone footprint on the Earth's surface.

In a 3D window, the DETECTOR graphical object displays a cone in space around the Earth.

In a Heliospace window, DETECTOR graphical object does nothing.

In a Spectral window, DETECTOR graphical object does nothing.

The DETECTOR graphical object supports the *Transparency* and *Color* options.

DETECTOR Inputs

To display a detector cone coming from a station or satellite, highlight an entry in the *Origin Stations* list and click the *Display* button. The detector properties can be adjusted using the *Properties* and *Look Dir* options. Characteristics can be created and saved for future use with the *File* option.

Origin Station: The *Origin Station* list presents a list of stations and satellites currently available for associating with a detector. To add a station to the *Origin Station* list, use the STATIONS graphics module to display a station. To add a satellite to the *Origin Station* list, run the SATEL-APP module and display a satellite using the SATELLITE graphics module.

Properties: The *Properties* switch accesses to the following detector cone properties.

- View Angle: The *View Angle* slider and text box are used to set the width in degrees of the detector cone.
- Solid: The *Solid* toggle button is used to display solid detector cones. By default only the silhouette edges of the detector cone are displayed.

Look Dir: The default look direction for a detector cone coming from a satellite and a station is toward the nadir and the zenith, respectively. The *Look Dir* switch provides access to the following detector look direction options:

- Fixed: The *Fixed* switch reveals slider and equivalent text fields used to adjust the *Pitch* and *Azimuth* direction.
  - Pitch: For a satellite detector with azimuth angle equal to zero degrees, a 90 (-90) degree pitch angle is parallel (anti-parallel) to the satellite geographic velocity vector. For a

station detector, a 90 (-90) degree pitch angle points the cone northward (southward).

Azimuth: For a satellite detector with a 90 degree pitch angle, a zero degree azimuth angle aligns the detector cone with the satellite geographic velocity vector. For a station detector with a 90 degree pitch angle, a zero degree azimuth angle directs the detector cone northward.

Tracking: The *Tracking* switch reveals a *Track Station* list. The detector cone look direction will be fixed on a station or satellite if an entry is highlighted. The detector cone will only remain visible while there is an open direct line-of-sight between the *Origin Station* and the *Track Station* objects. To add a station to the *Track Station* list, use the STATIONS graphics module to display a station. To add a satellite to the *Track Station* list, run the SATEL-APP module and display a satellite using the SATELLITE graphics module.

File: The *File* option allows the user to display pre-defined detectors as well as define new detectors and edit the list of saved detector descriptions. The save detector configurations can only be used when the *Look Dir: Fixed* option is selected (see above). The following input options are provided:

Detector Views: The *Detector Views* list presents a list of detector cones currently available for associating with the station or satellite highlighted in the *Origin Station* list. To display one of these detectors, highlight an entry in the list and click on the *Display* button. To save the current detector setting as a new entry in this list, use the *Name* and *Save* features detailed below.

Name: The *Name* text field represents the name to be assigned to a new detector entry that will appear in the *Detector Views* list. The current *Properties* and *Look Dir* settings will be associated with this name when saved.

Save: The *Save* button adds a detector called *Name* to the *Detector Views* list. The characteristics to be associated with the new detector are those currently appearing in the *Properties* and *Look Dir* settings.

Delete: The *Delete* button allows the user to remove a detector from the *Detector Views* list. To remove a detector, highlight its name in the *Detector Views* list and click on the *Delete* button.

DMSP

The DMSP graphical object is used to view 1-D plots and 2-D spectral plots of DMSP SSJ/4 & 5 and SSI/ES sensor data that were previously prepared using the DMSP Data Module.

The DMSP graphical object rendering is dependent on the window type.

In a 1D window, the DMSP graphical object will display a set of DMSP data derived quantities as a function of time.

In a 2D window, the DMSP graphical object does nothing

In a 3D window, the DMSP graphical object does nothing.

In a Heliospace window, DMSP graphical object does nothing.

In a Spectral window, the DMSP graphical object displays energy spectrograms of precipitating electron and ion particle counts and flux as a function of time for a single DMSP satellite orbit.

The DMSP graphical object supports the *Color Map* option.

DMSP Inputs

Before using this DMSP graphics module, a set of data files for a DMSP satellite orbit must first be processed using the DMSP Data Module. The *1D Plot* quantities described below are viewed using a 1D window (e.g., select the *Viewport* menu, then the option *Projection* and sub-option *One D*). The *Counts* and *Flux* quantities accessible via the *Data* button are viewed using a Spectral window (e.g., select the *Viewport* menu, then the options *Projection* and sub-option *Spectral*). See "DMSP Precipitating Particles: Data Versus Climatology" in the EXAMPLES section of this manual for a demonstration of basic module functions.

Data: The *Data* option button is used to select either *Counts* in units of counts/observation or *Flux* in units of log[#/(cm2-s-sr)] as the quantity to be viewed in the 2-D Spectral window. If no options appear, then the user must use the DMSP Data Module to process an orbit of data. Checking the *Display* option while a Spectral window is active will produce a 2D energy versus time plot in the Spectral window.

Eq. Edge: If the equatorward edge boundary of the diffuse auroral precipitation was contained in the DMSP data files processed, then selecting this option will cause the boundary locations to appear in the Spectral plot.

1D Plot: The *1D Plot* options listed here are quantities to be viewed in a 1-D window. Checking the *Display* option while a 1-D window is active will produce a 1-D plot of the selected quantity versus time in that window. If no plot appears, then the user must use the DMSP Data Module to process an orbit of data.

- None: No data has been selected for viewing in a 1-D window.
- Data Probe 0: Selecting the *Data Probe 0* option will cause a line to be drawn in the spectral plot window and the spectral data along that line will appear in the 1-D plot window. If this option is selected then the *X Axis*, *Y Axis*, and

Position options described below control the orientation and placement of the data probe line.

IEF-E, IEF-P — Integral energy flux of electrons (*IEF-E*) or protons (*IEF-P*) will be plotted by selecting these options.

INF-E, INF-P: — Integral number flux of electrons (*INF-E*) or protons (*INF-P*) will be plotted by selecting these options.

AE-E, AE-P: — Average energy of electrons (*AE-E*) or protons (*AE-P*) will be plotted by selecting these options.

Bx, By, Bz: — The magnetic field components (in nT) are measured down along the local vertical direction (Bx), along the forward direction (By; perpendicular to Bx), and "vertical" (Bz, perpendicular to both Bx and By) to the spacecraft orbit.

V Hori, V Vert: — Ion drift velocities (m/s) in the horizontal (*V Hori*) and vertical (*V Vert*) direction will be plotted by selecting these options.

The following BMode options apply only to J5 data available on DMSP F16 and future missions.

BMode:IEF-E,
BMode:IEF-P: — For the BMode pitch-angle selected in the DMSP Data Module, these options result in plots of the integral energy flux of electrons (*IEF-E*) or protons (*IEF-P*).

BMode:INF-E,
BMode: INF-P: — For the BMode pitch-angle selected in the DMSP Data Module, these options result in plots of the integral number flux of electrons (*INF-E*) or protons (*INF-P*).

BMode:AE-E,
BMode: AE-P: — For the BMode pitch-angle selected in the DMSP Data Module, these options result in plots of the average energy of electrons (*AE-E*) or protons (*AE-P*).

X Axis, Y Axis: — If the *1D Plot* option called *Data Probe 0* is selected, then selecting the *X Axis* or *Y Axis* option determines whether the data probe line will run vertically or horizontally, respectively, through the spectral plot. If the *Data Probe 0* option is not selected, then these options do nothing.

Position: — If the *1D Plot* option called *Data Probe 0* is selected, then the *Position* slider controls the vertical (if the *X Axis* option was selected) or horizontal (if the *Y Axis* option was selected) location in the spectral plot of the line defining the quantity to be assigned to the *Data Probe 0* option. The data to appear in the 1-D window will then represent the spectral plot content along the line. If the *Data Probe 0* option is not selected, then this option does nothing.

Type: The *Type* options are used to select how the linear data are plotted, i.e., as discrete points (*Point*), a solid line (*Line*), or stippled line (*Stipple 1* and *Stipple 2*).

Thickness: The *Thickness* slider controls the width of plotted points and lines.

X Axis: Displayed *X Axis* features are controlled by the following options:

- Enabled: The *Enabled* check box controls the display of axis labels.
- Grid: The *Grid* check box places grid lines at axis tic mark locations.
- Min, Max: The *Min* and *Max* text boxes are used to control the range of values plotted. After editing either value, the plot will update when the cursor is placed in any one of the other text boxes in the environment window.
- Auto: The *Auto* button adjacent to the *Min* and *Max* text boxes automatically resets the plot range to the minimum and maximum values of the data set.
- Format: The *Format* text box determines the format of the tic mark labels. "C"-like format statements are accepted, e.g., "%5.2f" will label the tics using floating point numbers with two decimal places. Substitute an "e" for "f" and exponential formatting will be used. After editing a *Format* text box, the display will update when the cursor is placed in any other text box in the environment window.
- Num Tics: The *Num Tics* text box controls the number of labels and tic marks along the axis. Update by placing the cursor in another text box.

Y-Axis: The *Y Axis* options are the same as the *X Axis* options described above with the following additional capabilities:

- Side:Left, Right: The *Left* and *Right* buttons determine the display side of the axis labels.
- Log: The *Log* check box activates the use of a log base 10 scale. When applied to number values less than or equal to zero, the *Log* function will display a "-6" on the log scale.

EARTH

The EARTH graphical object can be used to plot a representation of the Earth as well as surface grids, the day/night terminator, and political boundaries, and rivers. The color of all surface features is adjustable. Rendering of the EARTH graphical object is dependent on the window type.

In a 1D window, the EARTH graphical object does nothing.

In a 2D window, the EARTH graphical object plots outlines or solid representations of the Earth's continents. The horizontal axis is longitude; the vertical axis is latitude.

In a 3D window, the EARTH graphical object plots a sphere with either outlines or filled representations of the Earth's continents.

In a Heliospace window, EARTH does nothing.

In a Spectral window, EARTH does nothing.

The EARTH graphical object supports the *Clipping, Lights, Material*, and *Color* options.

EARTH Inputs

Outline Detail: The user can select any of the buttons in this section to determine how the Earth is drawn. The choices are:

- Textured: Draw the continents filled with a textured map.
- Geographic Bndys: Draw white outlines of geographic boundary features.
- Political Bndys: Draw yellow outlines of political boundaries.
- Rivers: Draw green outlines of rivers.

Grid Options: The selections within this section allow the user to place several different grids on the representation of the Earth. The choices are:

- Lat/Lon Grid: Render a grid showing geographic latitude and longitude. The default resolution is 10^{o}.
- Mag Dipole Grid: Render a grid showing magnetic latitude and longitude of the tilted dipole field. The default resolution is 10^{o}.
- CGM Grid: Render a grid showing magnetic latitude and longitude of the CGM field. The default resolution is $10^{o.}$
- Terminator: Draw a line at the terminator using the global UT.

Resolution: These up/down arrows determine the resolution with which outline features are rendered and rendering becomes more detailed as the resolution is decreased. The *Resolution* setting only affects outlined geographic boundaries, political boundaries, and rivers.

Detail Level: The database from which the outline features are rendered on the Earth is divided by "detail level". As *Detail Level* is increased, more minor geographic features are included on the plot. For example, with geographic boundaries, a detail level of one will render continents and

“major” islands. Increasing the detail level will increase the number of “minor” islands and other small geographic features included in the output. These up/down arrows only affect outlined geographic boundaries and rivers.

EMITTER

The EMITTER graphical object is used to view an emitter, such as a radar fan, located at a station or in orbit on a satellite. The stations and satellites to be associated with an EMITTER must have been displayed previously using the STATION graphics module and the SATEL-APP and SATELLITE modules, respectively.

The EMITTER graphical object rendering is dependent on the window type.

In a 1D window, the EMITTER graphical object does nothing.

In a 2D window, the EMITTER graphical object does nothing.

In a 3D window, the EMITTER will display the emitter fan in three-dimensional space around the Earth.

In a Heliospace window, EMITTER does nothing.

In a Spectral window, EMITTER does nothing.

The EMITTER graphical object supports the *Transparency* and *Color* options.

EMITTER Inputs

To display an emitter fan coming from a station or satellite, highlight an entry in the *Origin Station* list and click the *Display* button. The EMITTER properties can be adjusted using the *Properties* and *Look Dir* options. EMITTER characteristics can be created and saved to file for future use with the *File* option.

Origin Station: The *Origin Station* list presents a list of stations and satellites currently available for associating with an EMITTER. To add a station to the *Origin Station* list, use the STATIONS graphics module to display a station. To add a satellite to the *Origin Station* list, run the SATEL-APP module and display a satellite using the SATELLITE graphics module.

Properties: The *Properties* switch provides access to the following EMITTER fan properties.

- View Horizontal: The *View Horizontal* slider and text box are used to set horizontal width in degrees of the EMITTER fan.
- View Vertical: The *View Vertical* slider and text box are used to set the vertical width in degrees of the EMITTER fan.
- View Range(km): The *View Range* slider and text box are used to set the range in kilometers of the EMITTER fan.
- Solid: The *Solid* toggle button is used to display solid EMITTER cones. By default only the silhouette edges of the EMITTER cone are displayed.

Look Dir: The default look direction for an EMITTER cone coming from a satellite and a station is toward the nadir and the zenith, respectively. The *Look Dir* switch provides access to the following EMITTER look direction options:

Fixed: The *Fixed* switch reveals slider and equivalent text fields used to adjust the *Pitch* and *Azimuth* direction.

Pitch: For a satellite EMITTER with azimuth angle equal to zero degrees, a 90 (-90) degree pitch angle is parallel (anti-parallel) to the satellite velocity vector, respectively. For a station EMITTER, a 0 degree pitch angle points the cone northward tangent to the Earth's surface. Positive (negative) pitch angles direct the fan below (above) the horizon.

Azimuth: For a satellite EMITTER with a 90 degree pitch angle, a zero degree azimuth angle aligns the EMITTER cone with the satellite velocity vector. For a station EMITTER with a 0 degree pitch angle, a zero degree azimuth angle directs the EMITTER cone northward with positive (negative) azimuth angles rotating the fan eastward (westward).

Tracking: The *Tracking* switch reveals a *Track Station* list. The EMITTER fan look direction will be fixed on a station or satellite if an entry is highlighted. The EMITTER cone will only remain visible while there is an open direct line-of-sight between the *Origin Station* and the *Track Station* objects. To add a station to the *Track Station* list, use the STATIONS graphics module to display a station. To add a satellite to the *Track Station* list, run the SATEL-APP module and display a satellite using the SATELLITE graphics module.

File: The *File* option allows the user to display pre-defined EMITTERs as well as define new EMITTERs and edit the list of saved EMITTER descriptions. The saved EMITTER configurations can only be used when the *Look Dir: Fixed* option is selected (see above). The following input options are provided:

EMITTER Views: The *EMITTER Views* list presents a list of EMITTER cones currently available for associating with the station or satellite highlighted in the *Origin Station* list. To display one of these EMITTERs, highlight an entry in the list and click on the *Display* button. To save the current EMITTER setting as a new entry in this list use the *Name* and *Save* features detailed below.

Name: The *Name* text field represents the name to be assigned to a new EMITTER entry that will appear in the

EMITTER Views list. The current *Properties* and *Look Dir* settings will be associated with this name when saved.

Save: The *Save* button adds an EMITTER called *Name* to the *EMITTER Views* list. The characteristics to be associated with the new EMITTER are those currently appearing in the *Properties* and *Look Dir* settings.

Delete: The *Delete* button allows the user to remove an EMITTER from the *EMITTER Views* list. To remove an EMITTER, highlight its name in the *EMITTER Views* list and click on the *Delete* button.

FIELD-LINES

The FIELD-LINES graphical object is used to produce a depiction of magnetic field lines from the geomagnetic field model applications BFIELD-APP and BFOOTPRINT-APP and from the equatorial boundary produced by the AURORA science module.

The FIELD-LINES graphical object rendering is dependent on the window type.

In a 1D window, the FIELD-LINES graphical object does nothing.

In a 2D window, FIELD-LINES will project the lines onto a 2D grid of longitude (horizontal) and latitude (vertical).

In a 3D window, FIELD-LINES will display the lines in three-dimensional space around the Earth.

In a Heliospace window, FIELD-LINES does nothing.

In a Spectral window, FIELD-LINES does nothing.

The FIELD-LINES graphical object supports the *Clipping*, *Transparency*, *Lights*, *Material*, and *Color* options.

FIELD-LINES Inputs

Data:	The *Data* option menu is used to select the main data set and the type of field lines to be displayed. This option must be set before rendering is allowed. The option menu contains a list of valid, previously generated *BFIELD-APP, BFOOTPRINT-APP,* and *AURORA* items.	
Plot Type:	The plot type field determines how the FIELD-LINES should be rendered.	
	Field Lines:	Render the FIELD-LINES as separate field lines.
	Filled Surface:	Render the FIELD-LINES as a surface connecting the field lines.
Line Width:	These up/down arrows are used to select the width of the field lines in the display from 1 (thinnest) to 5 (thickest).	
Line Type:Smooth	This option renders smooth depictions of the field lines.	

GLOBAL INPUTS

The GLOBAL INPUTS graphical object is used to produce a line plot of the global input data values as a function of time. For dynamic runs, the time range is determined by the Start and End times entered at the top of the Environment Window. For static runs, the time range is fixed equal to 24-hours beginning with the Start time.

The GLOBAL INPUTS graphical object rendering is dependent on the window type.

In a 1D window, the GLOBAL INPUTS graphical object produces a line plot.

In a 2D window, GLOBAL INPUTS does nothing.

In a 3D window, GLOBAL INPUTS does nothing.

In a Heliospace window, GLOBAL INPUTS does nothing.

In a Spectral window, GLOBAL INPUTS does nothing.

The GLOBAL INPUTS graphical object supports the *Transparency* and *Color* options.

GLOBAL INPUTS Inputs

Value: The *Value* options represent global input parameters available for plotting. The choices include magnetic activity indices *Kp*, *Sum Kp*, *Ap*, *Ap15*, as well as the sunspot number *SSN*, *F10.7* cm solar radiation flux, the geomagnetic index *Dst*, and the equatorward edge of the diffuse aurora at midnight (*Eq Edge*). For details about these parameters please refer to the Global Parameters section of this user's manual. In dynamic mode, the text version of these values can be edited directly using the *Globals* pulldown menu.

Type: The *Type* options are used to select how the linear data are plotted, i.e., as discrete points (*Point*), a solid line (*Line*), or stippled line (*Stipple 1* and *Stipple 2*).

Thickness: The *Thickness* slider controls the width of plotted points and lines.

X Axis: Displayed *X Axis* features are controlled by the following options:

- Enabled: The *Enabled* check box controls the display of axis labels.
- Grid: The *Grid* check box places grid lines at axis tic mark locations.
- Min, Max: The *Min* and *Max* text boxes are used to control the range of values plotted. After editing either value, the plot will update when the cursor is placed in any one of the other text boxes in the environment window.
- Auto: The *Auto* button adjacent to the *Min* and *Max* text boxes automatically resets the plot range to the minimum and maximum values of the data set.

Format: The *Format* text box determines the format of the tic mark labels. “C”-like format statements are accepted, e.g., “%5.2f” will label the tics using floating point numbers with two decimal places. Substitute an “e” for “f” and exponential formatting will be used. After editing a *Format* text box, the display will update when the cursor is placed in any other text box in the environment window.

Num Tics: The *Num Tics* text box controls the number of labels and tic marks along the axis. Update by placing the cursor in another text box.

Y-Axis: The *Y Axis* options are the same as the *X Axis* options described above with the following additional capabilities:

Side: Left, Right: The *Left* and *Right* buttons determine the display side of the axis labels.

Log: The *Log* check box activates the use of a log base 10 scale. When applied to number values less than or equal to zero, the *Log* function will display a “-6” on the log scale.

Save: The *Save* button activates a *Save As* popup window used to save the 1-D displayed data to a text file. Designated file names should end with “.txt” for viewing convenience.

GRID

The GRID graphical object can be used to draw the calculation grid for the dataset. Rendering of the GRID graphical object is dependent on the window type.

In a 1D window, the GRID graphical object does nothing.

In a 2D window, the GRID graphical object plots the grid of the dataset with the horizontal axis representing longitude and the vertical axis representing latitude.

In a 3D window, the GRID graphical object draws the grid of the data set in three-dimensional space.

In a Heliospace window, GRID does nothing.

In a Spectral window, GRID does nothing.

The GRID graphical object supports the *Color* option.

GRID Inputs

Data:	The *Data* option menu is used to select the main data set for which the GRID is to be plotted. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously run science, data, and application data sets.
Plot as:	This input is used to specify whether the grid should be plotted as a series of *Points*, one to a grid vertex, or as a series of connected *Lines*.

IONSCINT-G

The IONSCINT-G graphical object is used to view GPS scintillation scenarios for fixed receiver platforms generated by the IONSCINT-G Science Module. Results can be viewed in 1-D plots of scintillation vs. azimuth or elevation and 2-D all-sky scintillation maps in azimuth and elevation.

The IONSCINT-G graphical object rendering is dependent on the window type.

In a 1D window, the IONSCINT-G graphical object will display a set of scintillation data (the S4 index) as a function of either elevation or azimuth angle.

In a 2D window, the IONSCINT-G graphical object does nothing

In a 3D window, the IONSCINT-G graphical object does nothing.

In a Heliospace window, IONSCINT-G graphical object does nothing.

In a Spectral window, the IONSCINT-G graphical object displays a 2D all-sky plot representing the view from a fixed platform of the S4 index as a function of elevation and azimuth angle for a given time.

The IONSCINT-G graphical object supports the *Color Map* and *Data Map* options.

IONSCINT-G Inputs

The IONSCINT-G Science Module must be run before using this IONSCINT-G graphics module. The *Data Probe* quantities described below are viewed using a 1D window (e.g., select the *Viewport* menu, then the option *Projection* and sub-option *One D*). The *S4Index* output accessible via the *Data* button are viewed using a Spectral window (e.g., select the *Viewport* menu, then the options *Projection* and sub-option *Spectral*).

Data:	The *Data* option button is used to select the scintillation output (i.e., the S4 index) to be viewed in active 1-D and/or 2-D Spectral windows. If no options appear, then the user must run the IONSCINT-G Science Module. Checking the *Display* option while a Spectral window is active will produce a 2D all-sky plot of the S4 index as a function of elevation (actually sin(elevation angle) and azimuth angle (0° for North, 90° for East, etc).
Data Probe:	Eight different *Data Probes* can be activated and viewed by checking the *Enabled* box while the corresponding probe number (0-7) is showing. If an all-sky plot is visible in an active spectral window, then a data probe line will be drawn in it and the data along that line can also be displayed in an active 1-D window. The *Sin(elev), Azimuth*, and *Position* options described below control the orientation and placement of the data probe. If no *Data Probe* is *Enabled*, then the following options do nothing.
Sin(elev), Azimuth:	Selecting one of these options to determine if the data probe appears in the spectral window as a circle of constant *Sin(elev)* or a radial line of constant *Azimuth*.

Position: The *Position* slider controls the value of *Sin(elev)* or *Azimuth* associated with the *Data Probe*.

1D Options

Type: The *Type* options are used to select how the linear data are plotted, i.e., as discrete points (*Point*), a solid line (*Line*), or stippled line (*Stipple 1* and *Stipple 2*).

Thickness: The *Thickness* slider controls the width of plotted points and lines.

X Axis: Displayed *X Axis* features are controlled by the following options:

- Enabled: The *Enabled* check box controls the display of axis labels.
- Grid: The *Grid* check box places grid lines at axis tic mark locations.
- Min, Max: The *Min* and *Max* text boxes are used to control the range of values plotted. After editing either value, the plot will update when the cursor is placed in any one of the other text boxes in the environment window.
- Auto: The *Auto* button adjacent to the *Min* and *Max* text boxes automatically resets the plot range to the minimum and maximum values of the data set.
- Format: The *Format* text box determines the format of the tic mark labels. "C"-like format statements are accepted, e.g., "%5.2f" will label the tics using floating point numbers with two decimal places. Substitute an "e" for "f" and exponential formatting will be used. After editing a *Format* text box, the display will update when the cursor is placed in any other text box in the environment window.
- Num Tics: The *Num Tics* text box controls the number of labels and tic marks along the axis. Update by placing the cursor in another text box.

Y-Axis: The *Y Axis* options are the same as the *X Axis* options described above with the following additional capabilities:

- Side:Left, Right: The *Left* and *Right* buttons determine the display side of the axis labels.
- Log: The *Log* check box activates the use of a log base 10 scale. When applied to number values less than or equal to zero, the *Log* function will display a "-13" on the log scale.

ISOCONTOUR

The ISOCONTOUR graphical object is used to produce a surface of constant value through a three-dimensional data set.

The ISOCONTOUR graphical object rendering is dependent on the window type.

In a 1D window, the ISOCONTOUR graphical object does nothing.

In a 2D window, ISOCONTOUR will project the outline of the constant value surface onto a 2D grid representing longitude (horizontal) and latitude (vertical).

In a 3D window, ISOCONTOUR will display the constant value surface through the data set in three-dimensional space around the Earth.

In a Heliospace window, ISOCONTOUR does nothing.

In a Spectral window, ISOCONTOUR does nothing.

The ISOCONTOUR graphical object supports the *Clipping*, *Transparency, Lights, Material*, *Color Map,* and *Data Map* options.

ISOCONTOUR Inputs

Data: The *Data* option menu is used to select the main data set the ISOCONTOUR is to be taken through. This option must be set before rendering is allowed. The option menu contains a list of valid, previously run science, data, and application data sets.

Contour Value: The *Contour Value* slider input determines the value of the constant surface. The values will range from the minimum to the maximum for the chosen data set. The numbers below the slider represents the relative and actual data values.

LINK

The LINK graphical object is used to view a line-of-sight link between stations and satellites or between separate satellites. The link can be colored with interpolated values from a selected data set. All stations to be used must have been displayed previously using the STATIONS graphics module. All satellites to be used must have been produced previously using the SATEL-APP application module and displayed using the SATELLITE graphics module.

The LINK graphical object rendering is dependent on the window type.

In a 1D window, the LINK graphical object produces a line plot of data values colored according to the parameter values along the link. The distance between the link ends is normalized to one.

In a 2D window, the LINK will project the link onto a 2D grid representing longitude (horizontal) and latitude (vertical).

In a 3D window, the LINK will display the link in three-dimensional space around the Earth.

In a Heliospace window, LINK does nothing.

In a Spectral window, LINK does nothing.

The LINK graphical object supports the *Color* and *Color Map* options.

LINK Inputs

Station 1, Station 2: The *Station 1* and *Station 2* lists contain all active station and satellite graphics objects that can be linked. To view a link between two stations, two satellites, or between a station and a satellite, select one entry from each Station list and click the *Display* button. To add a station to the lists, use the STATIONS graphics module to display a station. To add a satellite to the lists, run the SATEL-APP module and display a satellite using the SATELLITE graphics module.

Data: The *Data* button is used to select a main data set for display along the link. The option menu contains a list of valid, previously run science and application data sets. When a data set is selected, the link should appear colored, representing interpolated data values along the track. If the *Data* option is off, the orbit trajectory appears as a single color.

Num Steps: The *Num Steps* text box indicates the number of steps used in rendering colors representing data values along the link. The number of colors used to represent data along the link increases with the value of *Num Steps*.

Type: The *Type* options are used to select how the linear data are plotted, i.e., as discrete points (*Point*), a solid line (*Line*), or stippled line (*Stipple 1* and *Stipple 2*).

Thickness: The *Thickness* slider controls the width of plotted points and lines.

X Axis: Displayed *X Axis* features are controlled by the following options:

Enabled: The *Enabled* check box controls the display of axis labels.

	Grid:	The *Grid* check box places grid lines at axis tic mark locations.
	Min, Max:	The *Min* and *Max* text boxes are used to control the range of values plotted. After editing either value, the plot will update when the cursor is placed in any one of the other text boxes in the environment window.
	Auto:	The *Auto* button adjacent to the *Min* and *Max* text boxes automatically resets the plot range to the minimum and maximum values of the data set.
	Format:	The *Format* text box determines the format of the tic mark labels. "C"-like format statements are accepted, e.g., "%5.2f" will label the tics using floating point numbers with two decimal places. Substitute an "e" for "f" and exponential formatting will be used. After editing a *Format* text box, the display will update when the cursor is placed in any other text box in the environment window.
	Num Tics:	The *Num Tics* text box controls the number of labels and tic marks along the axis. Update by placing the cursor in another text box.
Y-Axis:	The *Y Axis* options are the same as the *X Axis* options described above with the following additional capabilities:	
	Side: Left, Right:	The *Left* and *Right* buttons determine the display side of the axis labels.
	Log:	The *Log* check box activates the use of a log base 10 scale. When applied to number values less than or equal to zero, the *Log* function will display a "-6" on the log scale.
Save:	The *Save* button activates a *Save As* popup window used to save the 1-D displayed data to a text file. Designated file names should end with ".txt" for viewing convenience.	

ORBIT-PROBE

The ORBIT-PROBE graphical object is used to produce a line plot through a data set along an orbit.

The ORBIT-PROBE graphical object rendering is dependent on the window type.

In a 1D window, the ORBIT-PROBE graphical object produces a line plot.

In a 2D window, ORBIT-PROBE does nothing.

In a 3D window, ORBIT-PROBE does nothing.

In a Heliospace window, ORBIT-PROBE does nothing.

In a Spectral window, ORBIT-PROBE does nothing.

The ORBIT-PROBE graphical object supports the *Transparency* and *Color* options.

ORBIT-PROBE Inputs

Path/Abscissa: This option menu is used to select an orbit from a list of valid, previously produced orbits.

Data/Ordinate: This option menu is used to select the main data set the ORBIT-PROBE is to be taken through. This option must be set before rendering is allowed. The option menu contains a list of valid, previously run science, data, and application data sets.

Type: The *Type* options are used to select how the linear data are plotted, i.e., as discrete points (*Point*), a solid line (*Line*), or stippled line (*Stipple 1* and *Stipple 2*).

Thickness: The *Thickness* slider controls the width of plotted points and lines.

Integral: For single-valued functions y = f(x), selecting the *Integral* box changes the 1-D x-y parameter plot to an integral plot with value y = Σf(x)dx.

X Axis: Displayed *X Axis* features are controlled by the following options:

- Enabled: The *Enabled* check box controls the display of axis labels.
- Grid: The *Grid* check box places grid lines at axis tic mark locations.
- Min, Max: The *Min* and *Max* text boxes are used to control the range of values plotted. After editing either value, the plot will update when the cursor is placed in any one of the other text boxes in the environment window.
- Auto: The *Auto* button adjacent to the *Min* and *Max* text boxes automatically resets the plot range to the minimum and maximum values of the data set.
- Log: The *Log* check box activates the use of a log base 10 scale. When applied to number values less than or equal

to zero, the *Log* function will display a "-6" on the log scale.

Format: The *Format* text box determines the format of the tic mark labels. "C"-like format statements are accepted, e.g., "%5.2f" will label the tics using floating point numbers with two decimal places. Substitute an "e" for "f" and exponential formatting will be used. After editing a *Format* text box, the display will update when the cursor is placed in any other text box in the environment window.

Num Tics: The *Num Tics* text box controls the number of labels and tic marks along the axis. Update by placing the cursor in another text box.

Y-Axis: The *Y Axis* options are the same as the *X Axis* options described above with the following additional capability:

Side: Left, Right: The *Left* and *Right* buttons determine the display side of the axis labels.

Save: The *Save* button activates a *Save As* popup window used to save the 1-D displayed data to a text file. Designated file names should end with ".txt" for viewing convenience.

ORBIT-SLICE

The ORBIT-SLICE graphical object is used to produce a data set slice that contains a satellite and the slice is produced in a plane defined relative to a specified orbit. The planes are defined using the coordinate system used to produce the data set or are planes perpendicular to or containing the satellite velocity vector. When a data set is produced using spherical coordinates, for example, the displayed data can be "slaved" to the altitude of the satellite by selecting the satellite radius (*P0*) as the defining coordinate.

The ORBIT-SLICE graphical object rendering is dependent on the window type.

In a 1D window, the ORBIT-SLICE graphical object does nothing.

In a 2D window, ORBIT-SLICE will project the slice onto the Earth's surface. Although allowed, usually this is not meaningful unless a geocentric radius coordinate is used to define the display slice.

In a 3D window, ORBIT-SLICE will display the slice through the data set in three-dimensional space around the Earth.

In a Heliospace window, ORBIT-SLICE does nothing.

In a Spectral window, ORBIT-SLICE does nothing.

The ORBIT-SLICE graphical object supports the options *Clipping*, *Transparency, Lights, Material, Color, Color Map,* and *Data Map*.

ORBIT-SLICE Inputs

Satellite: The *Satellite* option is used to slave the position of the slice to the position of a satellite along its orbit. This option must be set to an orbit before rendering is allowed. The option menu contains a list of valid, previously run orbits.

Data: The *Data* option menu is used to select the main data set the ORBIT-SLICE is to be taken through. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously run science, data, and application data sets.

Label: The label specifies the nature of the text written at the current position of the satellite. The available labels are:

- Sat Name: The satellite name set when it was created.
- Rad, Lat, Lon: The satellite position in spherical coordinates.
- X, Y, Z: The satellite position in Cartesian coordinates.
- Data Value: The interpolated data value at the satellite position.
- Time: The current time from the *Satellite position (%)* slider.

Pop Label: By default, if a marker is displayed, it will be positioned based on the satellite's three-dimensional location. Other objects may obscure it. If the

Pop Label toggle is on, the label will always be rendered in front of all other objects and will therefore always be visible.

Reference Frame: The *Reference Frame* section determines how the SATELLITE orbit should be rendered. The two coordinate options are geocentric (GEOC) and Earth centered inertial (ECI).

Geocentric: Render the SATELLITE orbit in geocentric (GEOC) coordinates. Since these coordinates are rigidly attached to the spinning Earth and represent a non-inertial frame, the trajectory will not be approximately elliptical in shape.

Inertial: Render the SATELLITE orbit in Earth centered inertial (ECI) coordinates. Here the trajectory will have an approximately elliptical shape. Note that the position of the orbit rotates when animation is selected because the inertial orbit plane is not fixed in geocentric coordinates.

Orbit Planes: The *Orbit Planes* toggle switches determine which orbital planes are rendered. The choices are:

P0: Draws a coordinate slice at the satellite position at a fixed value of the first coordinate of the system used to produce the data, e.g., P0 is the radius in spherical coordinates.

P1: Draws a coordinate slice at the satellite position at a fixed value of the second coordinate of the system used to produce the data, e.g., P1 is the latitude in spherical coordinates.

P2: Draws a coordinate slice at the satellite position at a fixed value of the third coordinate of the system used to produce the data, e.g., P2 is the longitude in spherical coordinates.

P3: Draws a plane containing the inertial orbital plane of the satellite.

P4: Draws a plane at the satellite position that contains the satellite's velocity vector and is perpendicular to the inertial orbital plane.

P5: Draws a plane at the satellite position and perpendicular to the satellite velocity vector.

Display Options: The *Display Options* field will allow the ORBIT-SLICE to be filled as colored or white contours, filled or discrete. Any combination of the options may be selected.

Filled: Render the ORBIT-SLICE as solid, filled, color contours.

Grey: If the grid extends beyond meaningful data in the data set, the points without valid data will be filled in as grey.

Contours: Render the ORBIT-SLICE as discrete white lines. The lines represent isovalues of the data evenly spaced between the data minimum and the data maximum. The number of contours is determined by the *Number of Contours* input.

Color The isovalue lines are colored according to the color bar to represent the magnitude of the isovalue.

Grid: An outline of the grid will be shown in the plane of the coordinate slice.

Number of Contours: The *Number of Contours* input slider determines the number of contour lines to be plotted between the data minimum and the data maximum if the *Display Options* selection is *Contours* or *Contours: Color*.

PLANE-SLICE

The PLANE-SLICE graphical object is used to produce a planar slice through a data set. The orientation of the slice is set by three user specified rotations. The PLANE-SLICE can be represented by filled color contours or discrete solid or colored contour lines. The grid within the slice can also be represented.

The PLANE SLICE graphical object rendering is dependent on the window type.

In a 1D window, the PLANE-SLICE graphical object does nothing.

In a 2D window, the PLANE-SLICE graphical object does nothing.

In a 3D window, PLANE-SLICE will display the planar slice through the data set in three-dimensional space around the Earth.

In a Heliospace window, PLANE-SLICE does nothing.

In a Spectral window, PLANE-SLICE does nothing.

The PLANE-SLICE graphical object supports the *Clipping*, *Transparency, Lights, Material, Color, Color Map*, and *Data Map* options.

PLANE-SLICE Inputs

Data:	This option menu is used to select the main data set the PLANE-SLICE is to be taken through. This option must be set before rendering is allowed. The option menu contains a list of valid, previously run science and application data sets.
Fill:	Render the PLANE-SLICE as solid filled color contours.
Show Gray:	If the grid extends beyond meaningful data in the data set, the points without valid data will be filled in as gray if this option is turned on.
Show Grid:	An outline of the grid will be shown if this option is turned on. The color of the grid lines can be adjusted using the *Color* option.
Contours: White	Render the PLANE-SLICE as discrete white lines. The lines represent isovalues of the data evenly spaced between the data minimum and the data maximum. The number of contours is determined by the *Number of Contours* slider. The color of the contours lines can be adjusted using the *Color* option.
Contours: Color	Similar to *Contours: White*, but the isovalue lines are colored according to the color bar to represent the magnitude of the isovalue.
Rotate X:	The *Rotate X* input slider rotates the position of the planar slice around the horizontal direction in the plane of the user’s computer screen.
Rotate Y:	The *Rotate Y* input slider rotates the position of the planar slice around the vertical direction in the plane of the user’s computer screen.
Rotate Z:	The *Rotate Z* input slider rotates the position of the planar slice around the direction normal to the plane of the user’s computer screen.

Translate: The *Translate* input slider translates the position of the planar slice along the direction perpendicular to the current position of the plane, as set by the rotation sliders.

Number of Contours: The *Number of Contours* input slider determines the number of contour lines to be plotted between the data minimum and the data maximum if one of the *Contour* options is activated.

RAY TRACE

The RAY TRACE graphical object is used to produce a depiction of the ionospheric rays traced through the PIM science model data sets. The PIM science module and RAYTRACE application module must be run before this graphics module can be used.

The RAY TRACE graphical object rendering is dependent on the window type.

In a 1D window, the RAY TRACE graphical object does nothing.

In a 2D window, RAY TRACE will project the lines onto a 2D grid of longitude (horizontal) and latitude (vertical).

In a 3D window, RAY TRACE will display the lines in three-dimensional space around the Earth.

In a Heliospace window, RAY TRACE does nothing.

In a Spectral window, RAY TRACE does nothing.

The RAY TRACE graphical object supports the *Clipping*, *Lights*, and *Material* options.

RAY TRACE Inputs

Data: The *Data* option menu is used to select the main data set and the type of field lines to be displayed. This option must be set before rendering is allowed. The option menu contains a list of valid, previously generated *RAYTRACE-APP* items.

Plot Type: The plot type field determines which ray features are displayed.

- Ray Lines: Render the ray lines.
- Ground Points: Render the transmitter location and mark all ground intersection points of the ray's path with the Earth's surface.
- Plasma Frequency: Render a 2D contour of the PIM generated plasma frequency in the plane of the traced rays. If the *Jones-Stephenson 3D* model was selected in RAYTRACE-APP to generate the rays, then the alignment of the rays and the contour will only be approximate.

Line Width: These up/down arrows are used to select the width of the traced ray lines in the display from 1 (thinnest) to 5 (thickest).

Line Type: Smooth Render smoothed depictions of the traced ray lines.

SATELLITE

The SATELLITE graphical object is used to view a satellite trajectory. The trajectory can be colored with interpolated values from a selected data set. The orbit trajectory must have been produced previously using the SATEL-APP application module.

The SATELLITE graphical object rendering is dependent on the window type.

In a 1D window, the SATELLITE graphical object does nothing.

In a 2D window, the SATELLITE will project the trajectory onto a 2D grid representing longitude (horizontal) and latitude (vertical).

In a 3D window, the SATELLITE will display the trajectory in three-dimensional space around the Earth.

In a Heliospace window, SATELLITE does nothing.

In a Spectral window, SATELLITE does nothing.

The SATELLITE graphical object supports the *Color* option.

SATELLITE Inputs

Satellite:	This option menu is used to select the SATELLITE orbit. This option must be set before rendering is allowed. The option menu contains a list of valid orbits produced previously using the SATEL-APP application module.
Data:	This option menu is used to select a main data set for display along the SATELLITE trajectory. The option menu contains a list of valid, previously run science, data, and application data sets. When a data set is selected, the orbit should appear colored, representing interpolated data values along the track. If the *Data* option is off, the orbit trajectory appears as a single color.
Label:	The label specifies the nature of the text written at the current position of the satellite. The available labels are: Sat Name: The satellite name set when it was created. Rad, Lat, Lon: The satellite position in spherical coordinates. X, Y, Z: The satellite position in Cartesian coordinates. Data Value: The interpolated data value at the satellite position. Time: The current time from the *Satellite position (%)* slider.
Pop Label:	By default, if a marker is displayed, it will be positioned based on the satellite's three-dimensional location. Other objects may obscure it. If the *Pop Label* toggle is on, the label will always be rendered in front of all other objects and will therefore always be visible.

Label Font: The *Label Font* selector controls the font size used for the annotation. The options include the machines *Default* font (size 20) and Times font (sizes *10, 20, 30, 40,* and *50*).

Reference Frame: The *Reference Frame* section determines how the SATELLITE orbit should be rendered. The two coordinate options are geocentric (GEOC) and Earth centered inertial (ECI).

Geocentric: Render the SATELLITE orbit in geocentric (GEOC) coordinates. Since these coordinates are rigidly attached to the spinning Earth and represent a non-inertial frame, the trajectory will not be approximately elliptical in shape.

Inertial: Render the SATELLITE orbit in Earth centered inertial (ECI) coordinates. Here the trajectory will have an approximately elliptical shape. Note that the position of the orbit rotates when animation is selected because the inertial orbit plane is not fixed in geocentric coordinates.

Thickness: The *Thickness* slider controls the width of the plotted orbit line.

STARS

References: Chapront-Touze, M., and J. Chapront, *Astron. Astrophys., 124*, 50 (1983)

Hoffleit, D., and W.H. Warren, Jr., *The Bright Star Catalogue*, Astronomical Data Center, NSSDC/GSFC (1991)

Montenbruck, O., and T. Pfleger, *Astronomy on the Personal Computer*, Springer-Verlag (1991)

Simon, J.L., P. Bretagnon, J. Chapront, M. Chapront-Touze, G. Francou, and J. Laskar, *Astron. Astrophys. 282*, 663 (1994)

STARS Overview

The STARS graphical object renders the celestial background as seen from the Earth for a given date and time. Stars as dim as visual magnitude eight, the planets, and the moon can be represented with this module. This module uses the Yale Bright Star catalogue, compiled by D. Hoffleit, as a stellar data base. Apparent equatorial coordinates are computed for the equinox of date from J2000 catalogued positions; these are corrected for stellar proper motion as well as the precession and nutation of the Earth. Lunar and planetary positions are computed from the FORTRAN codes ELP82B and PLANETAP, as obtained from the Astronomical Data Center of Goddard Space Flight Center. Apparent planetary positions in the Earth's frame of reference are corrected for precession and nutation.

In a 1D window, the STARS graphical object does nothing.

In a 2D window, STARS does nothing.

In a 3D window, the STARS graphical object plots the celestial sphere as a 3-dimensional background to the near-Earth space environment. An option exists to plot this background as a 3-dimensional sphere of varying radius.

In a Heliospace window, STARS does nothing.

In a Spectral window, STARS does nothing.

The STARS graphical object supports none of the standard options.

STARS Inputs

The STARS graphical module requires the following inputs:

Detail: The user can select buttons in this section to determine which objects are drawn in the celestial sphere. The choices are:

Stars:	Locate and draw the stars as white squares.
Stars: color:	Plot stars in color instead of white. Rendered colors are based on stellar spectral classification type (OBAFGKM) and are approximately those seen by the human eye from the Earth's surface.
Stars: circle:	Plot stars as circles instead of squares.
Sun:	Locate and draw the Sun.

Planets: Locate and draw the eight major planets. Planets are color coded shaded spheres, and are approximately the colors seen by the human eye through a small telescope - Mercury and Venus are white, Mars is red, Jupiter is a sandy brown, Saturn is yellowish, Uranus is aquamarine while Neptune is a dark turquoise.

Moon: Locate and draw the Earth's moon. Plotted as a white shaded sphere and is drawn to the same scale as the Earth 3D object.

Grid Options: Several types of grids may be placed upon the surface of the celestial sphere. The options are:

Lat/Lon Grid: Render a grid showing geographic latitude and longitude upon the celestial sphere to help an observer characterize the local sky at a given location. The resolution is ten degrees.

RA/DEC Grid: Render a grid showing Right Ascension and Declination of the background celestial sphere. Resolution is ten degrees.

Maximum Magnitude: This slider selects the visual stellar maximum magnitude (or minimum brightness) that will be plotted from the database (magnitude eight corresponds to minimum brightness setting). A total of 9110 stars are catalogued in this database. Relative brightness is modeled within the code by adjusting the pixel size and RGB color intensity of a plotted star, and corresponds approximately to the visual magnitude as catalogued in the Yale database.

Maximum Size (pixels): This slider controls the maximum pixel size used to plot the brightest star, i.e., Sirius. Down to an area of one pixel, the brightness of the star is represented by the size of the star in pixels. Below one pixel size, we reduce the intensity of the individual pixel. Thus, the larger the value of the maximum pixel size, the dimmer the star that will be visible in the window.

Celestial Radius: The radius of the celestial sphere, in Earth radii, can be adjusted with this slider when the *Finite Radius* option is activated (see below).

Finite Radius: Plot stars on the surface of a sphere with a radius determined by the *Celestial Radius* slider.

R=Infinity: Plot stars in a perspective view such that an arbitrarily large celestial sphere is used within which the viewer is effectively contained.

STATION

The STATION graphical object can be used to plot a labeled location on or above the surface of the Earth. Rendering of the STATION graphical object is dependent on the window type.

In a 1D window, the STATION graphical object does nothing.

In a 2D window, the STATION graphical object plots the station with label at the designated geographic latitude and longitude.

In a 3D window, the STATION graphical object plots the station with label at the designated geographic latitude, longitude, and altitude.

In a Heliospace window, STATION does nothing.

In a Spectral window, STATION does nothing.

The STATION graphical object supports the *Color* option.

STATION Inputs

Stations: The *Stations* list presents a list of stations currently available for display in 2D and 3D windows. To display a station, highlight it by clicking on it in the *Stations* list and click the *Display* button. To create a new station and add it to the *Stations* list, fill in the *Lat*, *Lon*, *Alt(Re)*, and *Label* text fields near the bottom of the environment options and click the *Add* button. To remove a station from the Stations list, highlight it by clicking on it in the Stations list and click the *Delete* button. Changes to the *Stations* list are saved in the file *$AFGS_HOME\models\data\STATIONS\stations.dat* which can also be edited directly.

Pop Label: The *Pop Label* switch forces the station location and label to be rendered in front of all other objects.

Label: The *Label* type selector specifies the nature of the text written at the current position of the station. The available labels are:

- Off: No label is displayed.
- Label: The station name is displayed.
- Rad, Lat, Lon: The station position is displayed in geographic spherical coordinates.
- X, Y, Z: The station position is displayed in geographic Cartesian coordinates.

Label Font: The *Label Font* selector controls the font size used for the annotation. The options include the machines *Default* font (size 20) and Times font (sizes *10, 20, 30, 40,* and *50*).

Lat: The *Lat* text field represents the station's North geographic latitude in degrees.

Lon:	The *Lon* text field represents the station's East geographic longitude in degrees.
Alt(Re):	The *Alt(Re)* text field represents the station's altitude in Km above the Earth's surface.
Label (text field):	The *Label* text field represents the name assigned to the station that will appear in the *Stations* list.
Add:	The *Add* button allows the user to add a station to the *Stations* list. The characteristics to be associated with the new station are those currently appearing in the *Lat*, *Lon*, *Alt(Re)*, and *Label* text boxes.
Delete:	The *Delete* button allows the user to remove a station from the *Stations* list. To remove a station, highlight its name in the *Stations* list and click on the *Delete* button.

VOLUME

The VOLUME graphical object is used to view the entire volume of a data set as a single three-dimensional object.

The VOLUME graphical object rendering is dependent on the window type.

In a 1D window, the VOLUME graphical object does nothing.

In a 2D window, the VOLUME graphical object does nothing.

In a 3D window, the VOLUME graphical object renders the entire data set as a single three-dimensional object.

In a Heliospace window, VOLUME does nothing.

In a Spectral window, VOLUME does nothing.

The VOLUME graphical object supports the *Clipping*, *Transparency, Color Map,* and *Data Map* options.

Hint: The *Transparency* option and the *Color Map: Alpha* option are very useful for creating viewable 3-D structures.

VOLUME Inputs

Data: The *Data* option menu is used to select the data set to be used by the VOLUME graphics option. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid data sets.

PARAMESH-COORDSLICE

The PARAMESH-COORD-SLICE graphical object is used to produce a slice or surface through a PARAMESH data set. The slice is produced along a constant of one coordinate direction. For example, if the data set was produced using a Cartesian grid, the PARAMESH-COORDSLICE graphical object produces a slice at constant X, Y, or Z value. Use the *Open Paramesh* option under the *File* pulldown menu to access Paramesh data files.

The PARAMESH-COORD-SLICE graphical object rendering functions only within the Heliospace window.

In a 1D window, the PARAMESH-COORDSLICE graphical object does nothing.

In a 2D window, the PARAMESH-COORDSLICE graphical object does nothing.

In a 3D window, the PARAMESH-COORDSLICE graphical object does nothing.

In a HelioSpace window, the PARAMESH-COORDSLICE graphical object will display the coordinate slice through the data set in three-dimensional space.

In a Spectral window, PARAMESH-COORDSLICE does nothing.

The PARAMESH-COORDSLICE graphical object supports the *Clipping*, *Transparency, Lights, Material, Color, Color Map, and Data Map* options.

PARAMESH-COORDSLICE Inputs

Data: The *Data* option menu is used to select the Paramesh data set through which the PARAMESH-COORDSLICE is to be taken. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously opened NRLMHD Paramesh data sets.

Cut Plane: The *Cut Plane* option defines the constant coordinate from the choices *C0*, *C1,* and *C2*. The generic names represent specific coordinate choices depending upon the grid type of the data set. For example, if the grid type of the data set is spherical, *C0* will produce a slice at constant radius; *C1* will produce a slice at constant latitude; *C2* will produce a slice at constant longitude. Similarly, if the data set has a Cartesian grid, the *C0*, *C1*, and *C2* will produce slices at constant X, Y, and Z, respectively.

Display Options: The *Display Options* field will allow the PARAMESH-COORDSLICE to be filled as colored or white contours, filled or discrete. Any combination of the options may be selected.

- Filled: Render the PARAMESH-COORDSLICE as solid, filled, color contours.
- Grid: An outline of the grid will be shown if this option is turned on.
- Values: Data values will be displayed at grid points.
- Contours: Render the PARAMESH-COORDSLICE as discrete black lines. The lines represent isovalues of the data

		evenly spaced between the data minimum and the data maximum. The number of contours is determined by the *Number of Contours* input.
	Contours: Color	Similar to *Contours*, but the isovalue lines are colored according to the color bar to represent the magnitude of the isovalue.
	Vectors:	Render white segments to represent the direction of the vector field of the selected vector type data at the Grid points within the PARAMESH-COORDSLICE. Selection of the parameter magnitude or one of its components all result in the complete vector. Vectors can be modified using the *Color* and *Norm* features.
	Vectors: Color	Vector segments are colored according to the color bar to represent its magnitude.
	Vectors: Norm	Vectors are all plotted using equal length segments to give only direction information.

Position Value:	The *Position Value* option determines the position of the coordinate slice. The position value represents the position (normalized to range from 0 to 1) along the constant coordinate. For example, if the dataset has a spherical grid and the *C0* coordinate is chosen, PARAMESH-COORDSLICE will produce a slice at constant radius. The position value input will select the value of the radius at which to produce the slice.
Number of Contours:	The *Number of Contours* input slider determines the number of contour lines to be plotted between the data minimum and the data maximum if the *Display Options* selection is *Contours* or *Contours: Color*.
Vector Scale Value:	The *Vector Scale Value* input slider is used to amplify the length of all vectors plotted by a constant scaling factor.

PARAMESH-FIELDLINES

The PARAMESH-FIELDLINES graphical object is used to produce fieldlines generated by tracing a vector field through a PARAMESH data set. Use the *Open Paramesh* option under the *File* pulldown menu to access Paramesh data files.

The PARAMESH- FIELDLINES graphical object rendering functions only within the Heliospace window.

In a 1D window, the PARAMESH-FIELDLINES graphical object does nothing.

In a 2D window, the PARAMESH-FIELDLINES graphical object does nothing.

In a 3D window, the PARAMESH-FIELDLINES graphical object does nothing.

In a HelioSpace window, the PARAMESH-FIELDLINES graphical object will display field lines of vector quantities such as magnetic field and momentum density through the data set in three-dimensional space.

In a Spectral window, PARAMESH-FIELDLINES does nothing.

The PARAMESH-FIELDLINES graphical object supports the *Clipping*, *Lights, Material, Color, Color Map, and Data Map* options.

PARAMESH-FIELDLINES Inputs

Data: The *Data* option menu is used to select the Paramesh data set through which the PARAMESH-FIELDLINES are traced. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously opened NRLMHD Paramesh data sets.

Two methods for defining the starting points of field-lines are provided, *Start Plane* and *User Defined*, and their selectors are located immediately under the *Data* button. Field-lines derived using both methods can be viewed simultaneously using a single PARAMESH-FIELDLINES graphical object.

Start Plane: The *Start Plane* method allows the generation of field-line sets originating from evenly distributed points in pre-defined planes. Field-lines starting from the following *Start Planes* can be displayed simultaneously:

X Min, Y Min, Z Min: Designate planes coincident with the minimum values of the X, Y, or Z coordinates.

X Mid, Y Mid, Z Mid: Designate planes coincident with the mid-point values of the X, Y, or Z coordinates.

X Max, Y Max, Z Max: Designate planes coincident with the maximum values of the X, Y, or Z coordinates.

Number of Starting Points: The number of field-lines traced from each *Start Plane* is the same and are evenly distributed along the remaining two dimensions. Each dimension is

divided in the designated number of cells and one field-line from the center of each one is traced.

X and Y: Number of starting points evenly distributed along the X and Y directions, respectively. For an X plane, the number of starting points in the Z direction is represented by the X entry. Similarly, for a Y plane, the number of starting points in the Z direction is represented by the Y entry.

User Defined: With the *User Defined* method, field-lines with arbitrary starting point locations can be added or deleted to the *Current Field Line* list by using the *Add* and *Delete* buttons, respectively. The settings for each field-line are displayed when its entry is visible in the *Current Field Line* list.

Current Field Line: The starting point location for the field-line entry visible in the *Current Field Line* list is controlled by position sliders and coordinate position values appear in text boxes under each slider.

X Position: Translate the field-line start point along the X axis (red axis of grid domain)

Y Position: Translate the field-line start point along the Y axis (green axis of grid domain)

Z Position: Translate the field-line start point along the Z axis (blue axis of grid domain)

Update: This button refreshes the field-line

The following common options appear at the bottom of the Environment Window.

Direction: Three options are provided designating the direction of field-line tracing

Forward: Trace the field-line in the direction of the vector field.

Back: Trace the field-line in the direction opposite the field.

Forward + Back: Trace the field-line in both the *Forward* and *Back* directions

Render Direction: The *Render Direction* option modifies the color intensity along the length of the field lines in a repeating pattern that indicates the direction of the vector. The bright end of each segment is oriented to designate the head of the vector. During use of Animation, these features will appear to move along the field line. To function, the field lines must be rendered as *Lines* or *Cylinders* (see below).

Off: The option is inactive.

	Type 1, 2, 3:	Selecting one of the *Type* indicators actives the *Rendering Direction* option. The three types differ in the length along the field line containing the bright-to-dim coloring pattern
Render As:	Three options are provided for modifying the appearance of field-lines	
	Lines:	Represent field-lines as simple lines.
	Lit Lines:	Represent field-lines as simple lighted lines.
	Cylinders:	Represent field-lines as 3-D cylinders with shadows.
Show Color:	Field-lines are colored according to the color bar to represent the magnitude of the field.	
Smooth:	Smooths the rendering of the field-lines.	
Line Width:	Adjust the apparent width of the field-lines	

PARAMESH-FIELDLINES-II

The PARAMESH-FIELDLINES-II graphical object is used to produce fieldlines generated by tracing a vector field through a PARAMESH data set. Use the *Open Paramesh* option under the *File* pulldown menu to access Paramesh data files.

The PARAMESH- FIELDLINES-II graphical object rendering functions only within the Heliospace window.

In a 1D window, the PARAMESH-FIELDLINES-II graphical object does nothing.

In a 2D window, the PARAMESH-FIELDLINES-II graphical object does nothing.

In a 3D window, the PARAMESH-FIELDLINES-II graphical object does nothing.

In a HelioSpace window, the PARAMESH-FIELDLINES-II graphical object will display field lines of vector quantities such as magnetic field and momentum density through the data set in three-dimensional space

In a Spectral window, PARAMESH-FIELDLINES-II does nothing.

The PARAMESH-FIELDLINES-II graphical object supports the *Clipping*, *Lights, Material, Color, Color Map,* and *Data Map* options.

PARAMESH-FIELDLINES Inputs

Data: The *Data* option menu is used to select the Paramesh data set through which the PARAMESH-FIELDLINES-II is traced. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously opened NRLMHD Paramesh data sets.

Two methods for defining the starting points of field-lines are provided, *Start Plane* and *User Defined*, and their selectors are located immediately under the *Data* button. Field-lines derived using both methods can be viewed simultaneously using a single PARAMESH-FIELDLINES-II graphical object.

Direction: Three options are provided designating the direction of field-line tracing

- Both: Trace the field-line in both the *Forward* and *Back* directions.
- Forward: Trace the field-line in the direction of the vector field.
- Back: Trace the field-line in the direction opposite the field.

Render As: Three options are provided for modifying the appearance of field-lines

- Lines: Represent field-lines as simple lines.
- Lit Lines: Represent field-lines as simple lighted lines.
- Cylinders: Represent field-lines as 3-D cylinders with shadows.

Smooth: Smooths the rendering of the field-lines.

Show Color: Field-lines are colored according to the color bar to represent the magnitude of the field.

Line Width: Adjust the apparent width of the field-lines.

Current Group: An organized collection or grouping of fieldlines can be displayed with this graphics module. The *Current Group* pulldown list shows the name given to the set of fieldline traces currently viewable with the module. If *NONE* is visible, then no fieldline groups are currently available for viewing. The following two options can be used to create/delete groups.

Create: The *Create* button generates a *Para-Mesh Field Line Create* popup window used to generate a new entry for the *Current Group* list. For each new group of fieldline starting points, the following options are available.

Name: The *Name* text box is used to create the name to appear in the *Current Group* list.

Type: The user can select to generate either a single *Point* or a collection of points arranged in a *Line, Circle, Plane*, or *Sphere*.

Start Position: The starting location for the next group of points can set as either the *Last Position* used by the previous group or as the *Origin*.

Axis: The axis of orientation for the newly created group will be the *X*, *Y*, or *Z* axis.

X Res (and/or) Y Res: The number of trace starting points along the X and Y coordinate directions is assigned using these text fields.

Delete: The *Delete* button will remove the group currently visible in the *Current Group* list.

Transform: The following transformation options enable the user to translate, rotate, and scale the *Current Group* of fieldline starting points.

Translate: Selecting the *Translate* option activates three sliders (*Translate X*, *Translate Y*, and *Translate Z*) that enable the user to move the *Current Group* of fieldlines along the X, Y, and Z coordinates.

Rotate: Selecting the *Rotate* option activates three sliders (*Rotate X*, *Rotate Y*, and *Rotate Z*) that enable the user to rotate the *Current Group* of fieldlines about the X, Y, and Z coordinates.

Scale: Selecting the *Scale* option activates the top slider which can then be used to spread or shrink the cluster of fieldline tracing start points.

PARAMESH-GRID

The PARAMESH-GRID graphical object is used to display the grid, block structure (e.g., leaf and parent block), and overall domain of a PARAMESH data set. Grid features can be color coded to reflect processor used and block level. Use the *Open Paramesh* option under the *File* pull-down menu to access Paramesh data files.

The PARAMESH-GRID graphical object rendering functions only within the Heliospace window.

In a 1D window, the PARAMESH-GRID graphical object does nothing.

In a 2D window, the PARAMESH-GRID graphical object does nothing.

In a 3D window, the PARAMESH-GRID graphical object does nothing.

In a HelioSpace window, the PARAMESH-GRID graphical object will display the Paramesh grid.

In a Spectral window, PARAMESH-GRID does nothing.

The PARAMESH-GRID graphical object supports the *Lights* and *Color* options.

PARAMESH-GRID Inputs

Data: The *Data* option menu is used to select the Paramesh data set to be used by the PARAMESH-GRID graphics option. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously opened NRLMHD Paramesh data sets.

Render Styles: The *Render Styles* field allows the PARAMESH-GRID to be displayed as discrete points, representing the grid cell vertices, or the lines connecting those grid cell vertices.

- Point: Display grid cell vertices as discrete points
- Outline: Display the lines connecting grid cell vertices

Color Method: The *Color Method* field allows the PARAMESH- GRID to be colored using a single user-selected color, or according to processor number, or grid level.

- Solid: Render the grid using a single solid color. The *Color* graphics option can be used to set *Grid* color when this method is selected.
- Processor Number: Set grid colors according to the assigned processor number, i.e., all grid points of a common color share a processor.
- Level: Set grid colors according to the assigned level number, i.e., all grid points of a common color represent grid points at the same level.

Render Blocks: Render a selection of PARAMESH- GRID blocks.

Leaf:	Display only *Leaf* grid cells. Leaf cells are those used to divide a *Parent* grid cells into smaller divisions.
Leaf + Parent:	Display both *Leaf* + *Parent* grid cells. *Parent* grid cells represent the initial divisions of the computation grid.
Max Depth:	Display only the smallest size grid cells representing the maximum depth within the grid.
Root Blocks:	Display only grid cells representing *Root Blocks*.
All:	Display *Root*, *Parent*, and *Leaf* grid cell blocks
Domain:	Display the overall domain of the grid with filled side panels and colored arrows representing the grid coordinate directions, i.e., for Cartesian coordinates the x, y, and z directions are show using red, green, and blue arrows, respectively. The *Color* graphics option can be used to set the color of the *Domain* and *Domain Lines* color.
Domain Hull:	Display grid domain cube only with colored axes (no filled side panels).

PARAMESH-ISOCONTOUR

The PARAMESH-ISOCONTOUR graphical object is used to produce a surface of constant value through a three-dimensional PARAMESH data set. Use the *Open Paramesh* option under the *File* pulldown menu to access Paramesh data files.

The PARAMESH-ISOCONTOUR graphical object rendering functions only within the HelioSpace window.

In a 1D window, the PARAMESH-ISOCONTOUR graphical object does nothing.

In a 2D window, the PARAMESH-ISOCONTOUR graphical object does nothing.

In a 3D window, the PARAMESH-ISOCONTOUR graphical object does nothing.

In a HelioSpace window, the PARAMESH-ISOCONTOUR graphical object will display the constant value surface through the data set in three-dimensional space.

In a Spectral window, PARAMESH-ISOCONTOUR does nothing.

The PARAMESH-ISOCONTOUR graphical object supports the *Clipping*, *Transparency, Material*, *Lighting, Material, Color Map,* and *Data Map* options.

PARAMESH-ISOCONTOUR Inputs

Data:	The *Data* option menu is used to select the main data set through which the PARAMESH-ISOCONTOUR is to be taken. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously opened NRLMHD Paramesh data sets.
Contour Value:	The *Contour Value* slider input determines the value of the constant surface. The values will range from the minimum to the maximum for the chosen data set. The number below the slider (0-to-1) corresponds to the range (minimum-to-maximum) of the data values shown on the color bar.

PARAMESH-VOLUME

The PARAMESH-VOLUME graphical object is used to view the entire volume of a PARAMESH data set as a single three-dimensional object. Use the *Open Paramesh* option under the *File* pulldown menu to access Paramesh data files.

The PARAMESH-VOLUME graphical object rendering functions only within the HelioSpace window.

In a 1D window, the PARAMESH-VOLUME graphical object does nothing.

In a 2D window, the PARAMESH-VOLUME graphical object does nothing.

In a 3D window, the PARAMESH-VOLUME graphical object does nothing.

In a HelioSpace window, the PARAMESH-VOLUME graphical object will display the entire volume of a data set in three-dimensional space.

In a Spectral window, PARAMESH-VOLUME does nothing.

The PARAMESH-VOLUME graphical object supports the *Clipping*, *Transparency, Lights, Material, Color Map,* and *Data Map* options.

Hint: The *Transparency* option and the *Color Map: Alpha* option are very useful for creating viewable 3-D structures.

PARAMESH-VOLUME Inputs

Data: The *Data* option menu is used to select the Paramesh data set to be used by the PARAMESH-VOLUME graphics option. This option must be set to a data set before rendering is allowed. The option menu contains a list of valid, previously opened NRLMHD Paramesh data sets.

Use Lighting: The *Use Lighting* option activates directional lighting on the rendered volume.

GRAPHICAL MODULE OPTIONS

This section describes the visualization controls and options available when running graphics modules. The options appear as buttons on the right side of each Graphics Module window and a set of controls for each will appear at the bottom of the Environment Window as options are selected. Options unavailable for a particular graphics module are grayed out. The effects of selecting and editing an option apply only to the graphics module currently highlighted in the Active Modules list. To alter the appearance of another graphics object, select its entry in the Active Modules list so that it is highlighted.

The following options are currently supported in AF-GEOSpace,

- **DISPLAY:** The *Display* option is used to display a graphics object in an active viewport. This option appears in all graphics modules.
- **INTERACTIVE:** The *Interactive* option controls whether graphical renderings are updated as changes are made to the graphic inputs. This option appears in all graphic modules.
- **USE TEXTURE**: The *Use Texture* mapping option improves the appearance of color data contours. This option appears in all graphics modules.
- **LIGHTING:** The *Lighting* option enables the *Lights* and *Material* options to be active.
- **CLIPPING:** The *Clipping* option applies clipping planes to a graphical object.
- **TRANSPARENCY:** The *Transparency* option controls the degree of transparency of a graphical object.
- **LIGHTS:** The *Lights* option controls lighting effects on a graphical object.
- **MATERIAL:** The *Material* option controls the light reflection properties of a graphical object.
- **COLOR:** The *Color* option controls the color of a graphical object.
- **COLOR MAP:** The *Color Map* option controls the color map representing a data set in the window color bar.
- **DATA MAP:** The *Data Map* option controls the range and linear/log scale used to display data.

The DISPLAY Graphical Option

The *Display* option determines whether the graphical object is displayed in the active plot window. It provides a convenient method for temporarily stopping the display of the object.

The INTERACTIVE Graphical Option

The *Interactive* option is used to force the appearance of displayed graphical object to update automatically as changes are made to the graphical settings. If *Interactive* is not selected, then some selection changes made in the graphics module window will not appear on screen until the *Display* button is toggled off/on.

The USE TEXTURE Graphical Option

The *Use Texture* option is used to improve the rendering of graphical objects by applying texture mapping smoothing algorithms to the data set before displaying. The use of this option provides the most accurate display of data sets so it is recommended that this option remain active.

The LIGHTING Graphical Option

The *Lighting* option enables the *Lights* and *Material* options to be active. If *Lighting* is not selected, then uniform light is applied on all objects.

The CLIPPING Graphical Option

The CLIPPING graphical option is used to produce the effect of clipping planes on a graphical object. The user can activate and define up to 6 clipping planes at a time. To activate and define an individual clipping plane: Select a plane (i.e., Plane 0, Plane 1, Plane 2, Plane 3, Plane 4, or Plane 5), activate it using the *Enabled* toggle switch, and adjust the rotation and translation sliders. The slider settings apply only to the Plane currently selected. The settings for individual planes are saved for the duration of a session. Additional clipping planes are created the same way and can be toggled On/Off to tailor 3D displays.

Clipping Parameters

Plane 0-5:	Select one of 6 independent clipping planes.
Rotate X:	The *Rotate X* input slider rotates the position of the clipping plane around the horizontal direction in the plane of the user's computer screen.
Rotate Y:	The *Rotate Y* input slider rotates the position of the clipping plane around the vertical direction in the plane of the user's computer screen.
Rotate Z:	The *Rotate Z* input slider rotates the position of the clipping around the direction normal to the plane of the user's computer screen.
Translate:	The *Translate* input slider translates the position of the clipping plane along the direction perpendicular to the current position of the plane, as set by the rotation sliders.
Enabled:	Toggle for activating the selected clipping plane, i.e., Plane 0.

The TRANSPARENCY Graphical Option

The TRANSPARENCY graphical option is used to produce the effect of transparency on a graphical object.

Transparency Parameter

Transparency:	The *Transparency* slider controls the fraction of light, “Alpha”, transmitted through the object. A value of 1.0 corresponds to complete opacity and a value of 0.0 corresponds to complete transmission, i.e., the object is invisible.

The LIGHTS Graphical Option

The LIGHTS option is used to model the effect of light on a graphical object. The user can activate and define up to 4 independent lighting sources plus activate 2 solar oriented lighting sources at a time. To activate and define an individual lighting source: Select a source (i.e., Light 0, Light 1, Light 2, or Light 3), activate it using the *Enabled* toggle switch, and adjust the properties of the source, e.g., Position. The slider settings apply only to the light source currently selected. The settings for individual sources are saved for the duration of a session. Additional light sources are created the same way and can be toggled using the *Enable* switch to tailor 3D displays.

Lighting Parameters

Ambient:	Set the ambient intensity of the light.
Specular:	Set the specular intensity of the light.
Diffuse:	Set the diffuse intensity of the light.
Position:	Set the position of the selected light source.
Red/Lat:	Specify the fraction of red or the latitude when position is selected.
Green/Long:	Specify the fraction of green or the longitude when position is selected.
Blue:	Specify the fraction of blue.
Light 0-3:	Select one of 4 independent lighting sources.
Sun:	Select a light source coming from the solar direction.
Opp Sun:	Select a light source coming from the anti-solar direction.
Enabled:	Toggle the lighting characteristics.

The MATERIAL Graphical Option

The MATERIAL option is used to modify the light reflection properties of graphical objects.

Material Parameters

Emission:	Set the emissiveness of material.
Diffuse:	Set the diffuseness of the material.
Specular:	Set the specular property of the material.
Shininess:	Set the shininess of the material.

The COLOR Graphical Option

The COLOR option is used to modify the color of graphical objects. Selecting the *Color* option while viewing a graphical module displays color selection inputs for the RGB and HSV color systems along with a list of graphical object components to which they may be applied. Colors can also be selected directly from the color wheel by placing the cursor in the color wheel and clicking the left mouse button. The current color selection appears in the solid colored rectangle below the color wheel. All color selections made will apply to the component of the graphical object current selected from the list appearing to the left of the sliders and the color wheel. Color changes remain in affect for the remainder of the session.

Color Parameters

RGB:	Selecting the *RGB* option displays a set of Red-Green-Blue sliders for blending color.
HSV:	Selecting the *HSV* option displays a set of Hue-Saturation-Value sliders for blending color.

The COLOR MAP Graphical Option

The *COLOR MAP* option is used to modify the mapping of colors assigned to data values shown in the color bar. This option is accessed using the *Color Map* button on the right side of the Graphics Module option windows.

Color Mapping Parameters

Color/data mapping characteristics are adjusted by manipulating plotted functions that appear in the Color Map Editor window representing each characteristic, e.g., the RGB or HSV color options. The representative functions consist of anchor blocks connected by lines that can be moved by clicking on anchor blocks and dragging them to new positions using the mouse. The *Color Map* options are:

Line: The *Line* option is used to connect all adjacent anchor blocks by line segments.

Curve: The *Curve* option is used to change the lines connecting all anchor blocks into a single simple curve.

RGB: Selecting the *RGB* option displays a set of Red-Green-Blue-Alpha options for blending color. Selecting a *RGB* option will result in its color map line appearing in the Color Map Editor window. The anchor blocks of each line can be moved vertically by clicking and dragging on it using the mouse. As an anchor block is moved, the color bars at the bottom of the Environment Window and in the graphics window will change. Interior anchor blocks can be added/removed using the *Insert*/*Delete* buttons described below. The *RGB* options are:

- Red: Specify the fraction of red.
- Green: Specify the fraction of green.
- Blue: Specify the fraction of blue.
- Alpha: Specify the fraction of light transmitted.

HSV: Selecting the *HSV* option displays a set of Hue-Saturation-Value-Alpha options for blending color. Selecting an *HSV* option will result in its color map line appearing in the Color Map Editor window. The anchor blocks of each line can be moved vertically by clicking and dragging on it using the mouse. As an anchor block is moved, the color bars at the bottom of the Environment Window and in the graphics window will change. Interior anchor blocks can be added/removed using the *Insert*/*Delete* buttons described below. The *HSV* options are:

- Hue: Specify the color hues.
- Sat: Specify the saturation of the colors.
- Value: Specify the value of the color intensities.
- Alpha: Specify the fraction of light transmitted.

Addition flexibility in prescribing color mapping is gained by inserting/removing interior anchor blocks. Interior anchor blocks can be moved horizontally and vertically with the mouse by clicking and dragging them. The tools for editing the anchor blocks are:

Insert: The *Insert* button is used to add an interior anchor block. To add a block, first use the mouse to click on the anchor block marking the left border of the segment to contain the new anchor block, then click on the *Insert* button and the new moveable anchor block will appear.

Delete: The *Delete* button is used to remove an interior anchor block. The end anchor blocks cannot be removed. To remove a block, use the mouse to click on the block, then use the *Delete* button and chosen anchor block will disappear.

The DATA MAP Graphical Option

The DATA MAP option is used to modify the range and linear/log scaling of the data displayed. The range of the data displayed must fall within the range of the data set being displayed.

Data Mapping Parameters

Data Min: The *Data Min* text window controls the minimum data value to be displayed. To update the displayed plotting scale after editing this text box, place the cursor in the *Data Max* text box or use the *Update* button. Selecting values less than the actual minimum of the data set is not permitted.

Data Max: The *Data Max* text window controls the maximum data value to be displayed. To update the displayed plotting scale after editing this text box, place the cursor in the *Data Min* text box or use the *Update* button. Selecting values greater than the actual maximum of the data set is not permitted.

Auto: The *Auto* option resets the displayed data minimum and maximum values to those of the original data set.

Log 10: The *Log 10* option changes the displayed data scale from linear to Log scale base 10 and vice versa. For $x \leq 0$, the value of Log10(x) will be set equal to –6.

DATA MODULES

Data modules provide methods for reading and plotting data sets produced and formatted external to AF-GEOSpace. The data modules are accessed through the data module manager that becomes visible when the *Data* option in the *Module* pulldown menu is activated. The data module manager consists of two lists - *Available Modules* and *Active Modules*. *Available Modules* are the modules that are currently supported by AF-GEOSpace. *Active Modules* are modules that have been created and used by the AF-GEOSpace user during the current session.

When initially accessed, the data module manager will show a list of data modules under *Available Modules*. Since no data modules have yet been created, the *Active Modules* list will be empty.

Currently, the following data modules are supported by AF-GEOSpace:

- **DMSP**: The DMSP data module enables the display (via the DMSP graphics module) of electron and ion energy spectra and integrated precipitating flux measured by the DMSP SSJ4/5 particle sensors.
- **EPHEMERIS:** The EPHEMERIS Data Module allows user-generated time-ordered data and satellite ephemeris to be loaded into AF-GEOSpace. After loading a file, data and satellite trajectory can be displayed using the Orbit Probe (1D) and Satellite (3D) graphical modules, respectively. This module facilitates data/model comparisons as the user-provided satellite trajectory can be used to sample other AF-GEOSpace environment models.
- **GRID:** The GRID Data Module allows user-generated files of gridded data in either spherical or Cartesian coordinates to be loaded into AF-GEOSpace. After loading a file, data can be displayed using all AF-GEOSpace graphical modules.

Running Data Modules

To run a data module, use the mouse to select the *Data* option in the *Module* pulldown menu and *Available Modules* and *Active Modules* lists will appear in the Environment Window. Click on the desired choice under *Available Modules*. For example, to create a new version of EPHEMERIS, click the mouse on *EPHEMERIS* in the *Available Modules* list. Choosing a data module will do two things: first, the choice is added to the *Active Modules* list; second, the options associated with the chosen data module will appear in the Environment Window. In general, each data module will have a different Environment Window representing the module specific inputs. Adjust/select the module inputs as required.

The *Delete* option in the *Edit* pulldown menu is used to remove the highlighted data module member of the *Active Modules* list. Note that all active graphics objects must be removed before the science module used to generate their data can be removed.

The DMSP Data Module

Model Name:	DMSP
Version:	2010
Developer:	Boston College and the Air Force Research Laboratory
References:	Brautigam, D.H., M.S. Gussenhoven, and D.A. Hardy, A Statistical Study on the Effects of IMF Bz and Solar Wind Speed on Auroral Ion and Electron Precipitation, *J. Geophys. Res, 96*, 5525-5538 (1991)

DMSP Overview

The DMSP Data Module enables the display of electron and ion energy spectra measured by the DMSP SSJ/4 (SSJ/5 for DMSP F16 and higher) and SSI/ES sensors as a function of time. The spectra are determined in the local satellite zenith direction once per second over 20 energy channels spanning the range 30 eV to 30 keV [e.g., *Brautigam et al.* (1991)]. The current version allows the user to view a list of daily data files for DMSP spacecraft F6 through F20 (F18 was the last spacecraft launched before this software release) and process an orbit from one file set for viewing with the DMSP Graphical Module. The five daily data files processed by this module for each spacecraft have names which include date and spacecraft identifiers in the following formats:

Four files with naming formats f*NNCCYYMMMDD*.dat (*NN* is the DMSP spacecraft number, *CC* is the two-character string "dm", "mp", "rp", or "sm", *YY* is the two-digit year, *MMM* is the 3-letter month abbreviation, and *DD* is the day of month) and one file with name format j4f*NNYYDOY* (where *DOY* is the 3-digit day of year) are required. For example, for the DMSP F13 spacecraft on 4 April 2003 (day of year 94) the user would require access to the following five files: f13dm03apr04.dat, f13mp03apr04.dat, f13rp03apr04.dat, f13sm03apr04.dat, and j4f1303095. As described in the following note, some sample DMSP data files are provided to allow users to exercise the DMSP Data and Graphical Modules (see "DMSP Precipitating Particles: Data Versus Climatology" in the EXAMPLES section of this manual). DMSP data files may be obtained from NOAA NGDC (http://www.ngdc.noaa.gov/dmsp/availability.html).

Note: If the DMSP data files to be accessed are always stored in a fixed location then they can be automatically located by the DMSP Data Module if a startup environment variable is set. At the time of installation, the startup file *$AFGS_HOME\bin\AFGeospace.bat* contains the following line:

```
set PLGS_DMSP_DATADIR=$AFGS_HOME\models\data\DMSP\2003
```

where *$AFGS_HOME* represents the AF-GEOSpace install directory. A few days of data for DMSP spacecraft F13 are stored within this directory. A 2010 directory is also included containing a weeks worth of F17 and F18 data. It is recommended that DMSP data be stored in the designated directory in individual yearly directories, e.g., in directories named 2003, 2004, etc. If data are to be routinely stored in a different fixed location, then the *AFGeospace.bat* file should be updated appropriately.

DMSP Inputs

The user can select the DMSP data source and individual quantities of interest by using the following DMSP Options:

Global Parameters: Year (Day, UT, Kp, SSN, and Ap are not used). If DMSP data are stored in directories named by years, as suggested in the above note, then the Year input helps locate appropriate files. Note that the entered year value is also used to construct some plotting labels by the DMSP Graphical Module so the proper year should be entered to avoid confusion.

Satellite: The *Satellite* selection feature provides access to daily DMSP data files for individual spacecraft *F06* through *F20* or for *All* available spacecraft data. If any data is located for the selected satellite(s), a list of J4 data files (with names formatted as j4f*NNYYDOY*) will appear in the sliding list below. Although they do not appear in the list, the other required DMSP data files associated with the J4 file selected will be processed when the *Run/Update* option of the *Edit* menu is used. If data files are not stored in the location designated in the *AFGeospace.bat* file (see note above), then use the *Browse* button described below.

Orbit Number (1-15): Because the DMSP orbit is approximately 90 minutes, the *Orbit Number* selector offers daily orbit options numbered 1-15.

J5 Mode B (1-6): [Note: This option is currently inactive]. The J5 sensor carried on spacecraft starting with DMSP F16 include particle data from 6 different pitch angle bins this *J5 Mode B* option prepares a selected bin for viewing. The values 1-6 correspond to six 15º directional zones (0º to 90º relative to local vertical).

Data Values: The six data options available for each DMSP daily files are as follows:

Integral Energy Flux: Prepare electron and proton integral energy flux for plotting in units of keV/(cm^2-s-sr) by selecting this option.

Integral Number Flux: Prepare electron and proton integral number flux for plotting in units of log[#/(cm^2-s-sr)] by selecting this option.

Average Energy: Prepare electron and proton average energy for plotting in units of keV by selecting this option.

Drift Velocity: Prepare horizontal and vertical drift velocities for plotting in units of m/s by selecting this option. Note that not all data file sets contain drift velocity data.

B Vector: Prepare magnetic field components Bx, By, and Bz for plotting in units of nT by selecting this option. Note that not all data file sets contain magnetic field data.

	Background:	Remove sensor contamination, i.e., false particle counts resulting from the presence of energetic radiation belt particle, by selecting this option.
Browse:	The *Browse* button is used to locate the directory containing the DMSP data file sets (Five files per satellite per day). Selecting the *Browse* button brings up an *Open* popup window. Locate the directory containing the data files, highlight one of J4 or J5 files, and hit the *Open* button to place the file names in the environment window.	

After all DMSP input selections are made, use the *Run/Update* option of the *Edit* menu to prepare the selected DMSP orbit data for viewing.

DMSP Outputs

The *Run/Update* option of the *Edit* menu is used to prepare the selected DMSP output quantities (i.e., integrated energy flux, integral number flux, average energy, drift velocity, and magnetic field along the selected DMSP orbit) for viewing using the DMSP Graphical Module in conjunction with 1-D and Spectral Viewports. Once the data has been displayed using the Graphical Module, the user may return to this module, adjust the options, and use the *Run/Update* option again to refresh the existing graphics. Note that the corresponding DMSP satellite orbit track is not currently automatically generated but see "DMSP Precipitating Particles: Data Versus Climatology" in the EXAMPLES section of this manual for instructions on generating the orbit using the SATEL-APP module and the appropriate orbital element files.

The EPHEMERIS Data Module

Model Name:	EPHEMERIS
Version:	2012
Developer:	AER, Inc., Boston College, and the Air Force Research Laboratory

EPHEMERIS Overview

The EPHEMERIS Data Module allows user-generated time-ordered data and satellite ephemeris to be loaded into AF-GEOSpace. After loading the data and satellite trajectory can be displayed using the Orbit Probe (1D) and Satellite (3D) graphical modules, respectively. This module is convenient for comparing observed satellite data with models as the user-provided satellite can be “flown” through other AF-GEOSpace environments.

EPHEMERIS Input

The EPHEMERIS input consists of a user-created ASCII data file containing a single header line and an arbitrary number of data lines describing a satellite position and data values associated with that position. The file format is described in the next section. To load a data file into AF-GEOSpace use the *Open File* button and the *Open* window appears. After selecting an ephemeris file, the *Open* button loads the data, closes the popup window, and places the chosen file’s name in the Environment Window just above the *Open File* button. The file contents should then be ready for display using the Orbit Probe and Satellite graphics modules. Note that the

EPHEMERIS Data File Format

The EPHEMERIS Data module accepts data files containing a single header line followed by an arbitrary number of data lines. The format is as follows:

Year Day Coordtype Ncolumns Caption-1 Caption-2 Caption-3
Time Coord-1 Coord-2 Coord-3 Column-1 Column-2 Column-3
Time Coord-1 Coord-2 Coord-3 Column-1 Column-2 Column-3
...
...
Time Coord-1 Coord-2 Coord-3 Column-1 Column-2 Column-3

The file *$AFGS_HOME\models\data\EPHEMERIS\ephemeris_sample2001_161.dat* is provided for the user to exercise this module. In the sample file, the *Year* and *Day* in the first line are equal to 2001 and 161, respectively. Note: For files formatted for the EPHEMERIS module released in AF-GEOSpace V2.0 to work, the *Year* value must be added to the beginning of the first line.

The elements of the header line are defined:

Year: Year (Integer)

Day: Day of year (Integer). Note that the Calendar Worksheet can be used to determine day of a given Year/Month/Day of Month.

Coordtype: Integer specifying the coordinate system used to represent the satellite location. The options are:

Coordtype = 0 for Cartesian GEOC system X, Y, Z measured in km)

Coordtype = 1 for Spherical GEOC system expressed in geocentric Radius (km), Latitude(degrees), and East Longitude (degrees)

Geocentric GEOC coordinate system: The Z axis is aligned with the north rotational pole, the X axis pierces the Greenwich Meridian on the equator (0 deg Long, 0 deg Lat), and the Y axis completes the right handed system.

Ncolumns: Integer number of columns of data to be read (limit 0 - 3) after the time and position.

Caption-1, -2, -3: Text captions for data columns (number of captions must match *Ncolumns*)

The elements the arbitrary number of data line are:

Time: Elapsed time in seconds from the start of the *Day* given in the header line.

Coord-1, -2, -3: Coordinate values depend on the coordinate type specified in the header line by *Coordtype*.

If *Coordtype* = 0, then (*Coord-1, Coord-2, Coord-3*) = (X, Y, Z) of the Cartesian GEOC system (km, km, km).

If *Coordtype* = 1, then (*Coord-1, Coord-2, Coord-3*) = (Radius, Latitude, East Longitude) of the spherical GEOC system (km, degrees, degrees).

Column-1, -2, -3: Data values (floats) for columns (number of data values must match *Ncolumns*)

Viewing EPHEMERIS Data and Satellite Orbit

The data loaded can be viewed in a 1D window using the Orbit Probe graphics module. After EPHEMERIS has been run, the *Path/Abscissa* and *Data/Ordinate* buttons in the Orbit Probe Environment Window will contain an option labeled *AppReadOrbit* representing the ephemeris data from this module.

The orbit represented by the *Coord-1, -2, -3* values can be displayed in a 3D window using the Satellite graphic module by selecting the satellite named EPHEMERIS. The orbit can also be colored to correspond to the loaded data by selecting a data option using the *Data* button.

To animate 1D or 3D plots containing Ephemeris data, the Global time interval (or the time interval in the *Animate* window) must encompass the *Year*, *Day* and *Times* in the Ephemeris file. For this reason, it is convenient to include the day number in the ephemeris data file name. Note that if the satellite locations are entered using Cartesian X, Y, Z (*Coordtype* = 0), they are automatically translated into Spherical coordinates (with radius in Re) for output displays.

The GRID Data Module

Model Name: GRID Data

Version: August 2009

Developer: AER, Inc. and the Air Force Research Laboratory

GRID Overview

The GRID Data Module allows a user-generated file of 3-D gridded data in either spherical or Cartesian coordinates to be loaded into AF-GEOSpace. After loading a file, data can be displayed using all AF-GEOSpace graphical models. This module is convenient for comparing gridded output from external models with each other and with the model environments of AF-GEOSpace and extracting model results along portions of satellite orbits.

GRID Input

The GRID input consists of a user-created ASCII data file formatted as described in the next section. The file *$AFGS_HOME\models\data\GRIDDATA\griddata_sample.dat* is provided for the user to exercise this module. To load a data file into AF-GEOSpace use the *Select File* button and an *Open* popup window appears. After selecting a GRID Data file, the *Open* button loads the data, closes the popup window, and places the chosen file's name in the Environment Window just above the *Select File* button. When a properly formatted data file is selected, the header information in the file is displayed so the user can *Select data values to read* by highlighting, i.e., clicking on, each desired data parameter to be loaded, and then selecting *Run/Update* from the *Edit* menu. The gridded data will then be loaded into memory and ready for display. Note that not selecting at least one parameter from the list will result in a generic popup error message. Other error messages are displayed when necessary, but note that some of these are currently only shown in one of the text shell windows. Note that the *Grid Tool* option in the *Edit* menu can be used before selecting *Run/Update* to specify internal spherical display grid characteristics. After using *Run/Update*, the *Data Tool* option in the *Edit* menu can be used to examine actual grid point locations and the parameter values loaded for display.

GRID Data File Format

The GRID Data module accepts data files containing a single header line followed by an arbitrary number of data lines. The contents of the file header are verified to contain the necessary keywords, parameters and information; error messages are displayed if the requirements are not met. Data values of magnitude 3.0×10^{38} and greater are considered invalid values, and are so honored in the graphical displays. The grid locations may be specified in terms of radius, latitude, and longitude values, and/or GEOC geocentric Cartesian X, Y, Z coordinates. Some alternative coordinate options are described in the data file header description below. A maximum of 32 data values may be loaded simultaneously. The data values are mapped to a regularly-spaced geocentric grid. When multiple data values are assigned to the same grid point, the maximum value is used.

There is no limit to the number of data points contained in a file but larger numbers will, of course, require more read time and computer memory resources.

The file can contain any number of leading comment lines, each starting with a '#' character. The Grid Data module only examines these comment lines following a line with '`# GRIDDATA`'. An example header is shown below, and a line-by-line description and explanation follows:

```
     # example Grid Data file header
     # ONERA IGRF magnetic field 2004/001 00:00 UT
     #   ~~ any number of leading comment lines, starting with a '#'
     #
a)   # GRIDDATA
b)   # SPEC 6371.2 31371.2 500.0 10.0 10.0
c)   # LABELS index rad colat lon geox geoy geoz Bx By Bz Angle Bmag
d)   # UNITS index km deg deg km km km unit unit unit deg nT
e)   # EXCL 0 1 1 1 1 1 1 1 1 1 0 1
     1 6371.2  10.0   0.0  1106.3473 0.0000 6274.4072  -0.29053679
     -0.01779209 -0.95669839 -73.07731  5.430498251e+04
     2 6371.2  10.0  10.0  1089.5394 192.1152 6274.4072  -0.28753001
     -0.05122019 -0.95640106 -73.01888  5.441620738e+04
     3 6371.2  10.0  20.0  1039.6264 378.3931 6274.4072  -0.27717132
     -0.08372591 -0.95716563 -73.16953  5.464138182e+04
     4 6371.2  10.0  30.0  958.1248 553.1736 6274.4072  -0.25962456
     -0.11439485 -0.95891027 -73.51827  5.497171473e+04
     …
     …
```

Required line 'a', starting with "`# GRIDDATA`", is the first line that will be recognized by the Grid Data module. This line must be before any other of the other specification lines. The other specification lines may be in any order, as long as they appear before the first line of data.

Optional line 'b', starting *with "`# SPEC`",* describes the spherical grid used in the display of the data in the file. The values, in this specific order, are as follows: radius (R_e or km) or altitude (km) minimum, maximum, and increment, latitude increment (deg), and longitude increment (deg). When this line is omitted, the spherical grid ranges and increments will be automatically ascertained from the data file contents. In general, at least three corner grid points need to be populated to get a color block/triangle, thus if input points are too sparse for the grid then data limits will be detected but no graphics can be generated. The grid configuration may also be modified via the *Grid Tool* option of the *Edit* menu prior. Note that defining a grid which is much finer than that of the data provided can result in, for example, stripped coordinate slices.

Required line 'c', starting with "`# LABELS`", lists the space-separated data name labels for each of the file's data columns. Specific data name labels are used for indicating which of the grid coordinate columns are available in the file. Not all need be present.

- '`geox`', '`geoy`' and '`geoz`' correspond to the GEOC Cartesian XYZ coordinates (in km).
- '`rad`' or '`radius`' correspond to radius (in km, or R_e if value <50)
- '`alt`' or '`altitude`' correspond to altitude (in km)
- '`lat`' or '`latitude`' correspond to latitude (-90 to +90 deg)
- '`colat`' or '`colatitude`' correspond to colatitudes (0 to 180 deg)
- '`lon`' or '`longitude`' correspond to longitude (-180 to +360 deg)

Any labels not fully matching these specific keywords will be interpreted as data parameters. These data parameter labels will be shown in the Grid Data module user interface, the graphical display data list, and be shown at the top of the color scale legend of the graphical display.

Required line 'd', starting with "`# UNITS`", lists the corresponding space-separated unit labels associated with the data name labels on line 'c'. These labels will be shown at the bottom of the color scale legend of the graphical displays.

Optional line 'e', starting with "`# EXCL`", enables certain columns of data to be excluded from being recognized as data parameters for display. This is useful for excluding columns containing character strings, date/time strings, or values with no meaning to the other data (i.e. line counter). Values of '`1`' indicate data parameters to be included, and '`0`' to be excluded. The number of values specified on this line must match those for the labels and units. This example shows that the first column, 'index', and the 11th column, 'Angle', will be ignored.

All remaining lines of the file contain the grid coordinate and data values, as specified in the header lines.

Note that missing/misspelled required key words (`GRIDDATA, LABELS, UNITS`), too few/many entries in required lines, or excluding one of three coordinate values will result in no parameter choices appearing in the data values box and the appearance of an "error running model" popup.

Data values in the file are assumed to be space-separated integer or floating point values on each line, corresponding to the specified column labels. Data values greater or equal to 3.0×10^{38} are considered to be the special 'No Data' value, and will not be shown in the graphical display. Any instances of '`NaN`' or '`Inf`' should be replaced with a 'No Data' value. All character strings used to specify `LABELS` and `UNITS` must be free of any internal spaces so they will be read as single entries associated with a given column.

As the file is processed, the coordinate values are first read from the line, and converted to radius, latitude and longitude if required. If these coordinates do not match up to the spherical grid points as defined in line 'b' (or the defaults), the nearest grid point is used. The selected data values are read from the rest of the line and are loaded into memory associated to the spherical grid point. In the case where more than one set of data values is associated to the same spherical grid point, the maximum data values are retained. Any spherical grid points without any data are filled with the special 'No Data' value.

While there is no limit to the number of positions in the spherical grid definition, nor a limit on the number of grid positions specified in the file, an excessive number of points will cause long file processing times and the memory required could potentially surpass the amount available on the host computer.

GRID Data Outputs

The GRID Data module returns a static 3D Gridded Data Set of the quantities listed in the `LABELS` line of the user-generated data file.

WORKSHEET MODULES

Worksheet modules provide auxiliary tools that are often helpful in AF-GEOSpace calculations. The worksheet modules are accessed through the worksheet module manager that becomes visible when the *Worksheet* option in the *Module* pulldown menu is activated. The worksheet module manager consists of two lists - *Available Modules* and *Active Modules*. *Available Modules* are the modules that are currently supported by AF-GEOSpace. *Active Modules* are modules that have been created and used by the AF-GEOSpace user during the current session.

When initially accessed, the worksheet module manager will show a list of worksheet modules under *Available Modules*. Since no worksheet modules have yet been created, the *Active Modules* list will be empty.

Currently, the following worksheet modules are supported by AF-GEOSpace:

- **CALENDAR:** A calendar showing month and day, day of year, and modified Julian day.

- **COORD_TRANSFORM**: Perform coordinate transformations on point locations using different coordinate systems (GEOC, GSM, SM, GEI) and coordinate geometries (Cartesian, Cylindrical, Spherical) at a given Year, Day, and UT.

Running Worksheet Modules

To run a worksheet module, use the mouse to select the *Worksheet* option in the *Module* pulldown menu and *Available Modules* and *Active Modules* lists will appear in the Environment Window. Click on the desired choice under *Available Modules*. For example, to create a new version of CALENDAR, click the mouse on *Calendar* in the *Available Modules* list. Choosing a worksheet module will do two things: first, the choice is added to the *Active Modules* list; second, the options associated with the chosen worksheet module will appear in the Environment Window. In general, each worksheet module will have a different Environment Window representing the module specific inputs. The outputs of worksheet modules are displayed in the same interactive Environment Window with the inputs. The user edits text boxes and sets selectors in the Environment Window and then places the cursor in some other text box to run the module and update the displayed result.

The *Delete* option in the *Edit* pulldown menu is used to remove the highlighted worksheet module member of the *Active Modules* list.

The CALENDAR Worksheet Module

Model Name:	Calendar
Version:	1996
Developer:	Rodger Biasca, Boston College
References:	NONE

CALENDAR Overview

The CALENDAR Worksheets module displays a calendar showing a specified month. If the Year (Month) text box is edited directly, the calendar updates when the cursor is placed inside the Month (Year) text box or by exiting and re-entering the Calendar worksheet.

CALENDAR Inputs

The CALENDAR worksheet module requires the following inputs:

Year:	The year of the calendar to display. *Year* values can be changed by editing the Year text box or by advancing the month using the up/down arrow buttons next to the *Month* text box.
Month:	The month of the calendar to display. Month values can be changed by editing the text box or by using the arrow buttons.

CALENDAR Outputs

CALENDAR displays the specified month of the specified year. The dates include day of year (DOY) and modified Julian day (MJD = 0 on 1 Jan 1950).

The COORD-TRANSFORM Worksheet Module

Model Name: COORD-TRANSFORM

Version: 2006 (includes IGRF 2005 updates for magnetic coordinates)

Developer: Boston College and Air Force Research Laboratory

References: Bhavnani, K.H., and R.P. Vancour, Coordinate Systems for Space and Geophysical Applications, *PL-TR-91-2296*, Phillips Laboratory, Hanscom AFB, MA (1991), ADA 247550

Russell, C.T., Geophysical Coordinate Systems, *Cosmic Electrodynamics, 2*, 184-196 (1971)

COORD-TRANSFORM Overview

The COORD_TRANSFORM worksheet module allows the user to perform a coordinate transform of a single point.

COORD-TRANSFORM Inputs

The COORD-TRANSFORM worksheet module requires the following inputs:

Year/Day/UT: The year, day of year, and UT at which to perform the coordinate conversion.

Inputs: The geometry and coordinate system options for the input point are:

- Geometry: The Geometry options for the input point are:
  - Cartesian: Generate a grid in Cartesian geometry.
  - Cylindrical: Generate a grid in cylindrical geometry.
  - Spherical: Generate a grid in spherical geometry.
- Coord System: The *Coord System* options for coordinate system of the input point are:
  - GEOC: Geocentric coordinate system: The Z axis is aligned with the north rotational pole, the X axis pierces the Greenwich Meridian on the equator (0 deg Long, 0 deg Lat), and the Y axis completes the right handed system.
  - GSM: Geocentric solar magnetospheric coordinate system: The X axis points to the Sun. The Z axis is perpendicular to X and lies in the plane containing the magnetic dipole axis. The Y axis completes the right handed system and is positive towards dusk.

SM: Solar magnetic coordinate system: The X axis is perpendicular to Z and lies in the plane containing the Z axis and the Earth-Sun line. The Z axis is coincident with the magnetic dipole axis. The Y axis completes the right handed system and is positive towards dusk.

GEI: Geocentric equatorial inertial coordinate system: The Z axis is the same as for the geocentric coordinate system (*GEOC*). The X axis points in the direction of the first point of Aries (vernal equinox). The Y axis completes the right handed system. The angle between the X axis and Greenwich Meridian is set by the UT from the animation widget.

C0, C1, C2: The three coordinate components of the input point are entered by editing text boxes with names that change according to the *Geometry/Coord System* combination selected.

Outputs: The geometry and coordinate system options for the output point are the same as for the input point.

COORD-TRANSFORM Outputs

COORD-TRANSFORM displays the three components of the output point in the new units at the bottom of the Environment Window. These values are updated every time a *Geometry* or *Coord System* selection is changed or whenever a *Year, Day, UT*, *C0, C1,* or *C2* text box is edited and the cursor is then placed in another text boxes.

EXAMPLES

This section provides a set of detailed examples demonstrating some of the modeling and display capabilities of AF-GEOSpace. Each one starts with a brief statement describing the goal of the example. It is the authors' belief that the most efficient way to learn the program is by working through an example or two.

Example titles containing the comment "(Dynamic)" make use of the AF-GEOSpace dynamic run capability, i.e., the environment will be calculated for a series of time steps using a history of global input parameters. Examples without this designation are "Static", i.e., environments are calculated at a single time using one set of global parameters.

Example titles containing the comment "(V2.5.1 Only)" require Science or Application modules provided only in AF-GEOSpace Version 2.5.1 distributed to pre-approved government institutions and their agents. See *Release Notes on the User's Manual and Software* at the beginning of this document.

1) Space Particle Hazards

The following example demonstrates the use of the DMSP aurora Science Module (AURORA), the CRRES electron and proton radiation belt flux Science Modules (CRRESELE, CRRESPRO), the Satellite Application Module (SATEL-APP), and a variety of visualization tools including animated satellite orbits, links, and detector cones.

Goal: View auroral electron precipitation patterns and the 3-D distribution of 1.6 MeV electrons and 10.7 MeV proton radiation belt fluxes during magnetically active times relative to spacecraft in Low, Medium, Geosynchronous, and High Earth Orbit (a.k.a., LEO, MEO, GEO, and HEO). Build satellite-to-ground communications links and satellite detector cones.

Start an AF-GEOSpace session and set global input parameters,

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this run, set the date and time in the Environment Window by editing the text boxes to read: *Start:Year*=1996, *Day*=315, and *UT*=18:00. Select the *Archive* option using the *Globals* selector to the right of the time inputs and the values of the Kp geomagnetic index, sunspot number (SSN), F10.7 cm radio flux, and the Ap geomagnetic index for this time will be copied from archived NGDC parameters (*Kp*=1.7, *SSN*=12, *F10.7*=69.6, and *Ap*=6). Reset *Kp*=5.0 and *Ap*=25 to represent a magnetically active period by manually editing the corresponding text boxes.

Create a 3-D graphic of the Earth with the Air Force Research Laboratory location displayed,

- Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Earth*. An Earth object will be added to the *Active Modules* list and a set of Earth Options will appear in the Environment Window.

- Under Outline Detail, leave *Geographic Bndys* selected. Under Grid Options select *Lat/Lon Grid*. Check the *Display* box and the Earth globe will appear in the default 3D window.

- To place a station marker representing the location of AFRL, scroll down the *Available Modules* list and select *Station* and a *Station* object will be added to the *Active Modules* list. Highlight the *AFRL* entry in the *Stations* list and click *Display* and an AFRL label should appear in the 3D window at the location (Alt (Re)= 1.0, Lat = 42.30, and Lon = -71.05) representing AFRL. Note: Station entries can be added by editing the four text boxes and clicking the *Add* button. Stations can be removed from the list by highlighting the entry in the *Stations* list and clicking on the *Delete* button. The *Pop Label* control can be used to make the station always visible. All changes to the Stations list will be saved for future sessions.

- With no data plotted, use the *Viewport* menu to turn off *Show Color Bar*.

- The Earth's size can be scaled in the 3D Window using the right mouse button. With the cursor in the 3D Window, depress the right button and draw the mouse toward yourself. Rotate the Earth so that the AFRL location marker is visible by depressing the left button and moving the mouse sideways.

Display a Time/Date Label in the Active Graphic Window,

- Select *Annotation* from the *Available Modules* list. An Annotation object will be added to the *Active Modules* list and a set of Annotation Options will appear in the bottom of the Environment Window. To display a time label in the graphics window, place a check mark in the *Show Date* box and click *Display* and a time/date label will appear in the far lower left corner of the graphic window. Move the *X Position* and *Y Position* sliders to a value of approximately 0.04 to make them easier to read.

Create and display an orbiting Low Earth Orbit (LEO) satellite,

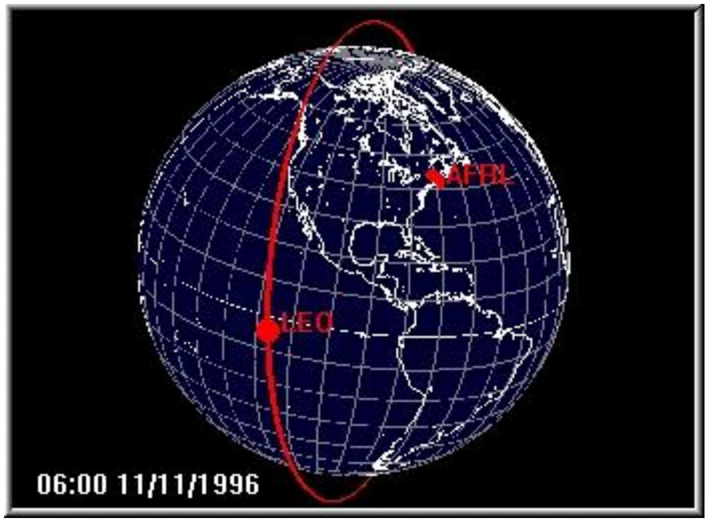
- Select the *Applications* option from the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and click on *SATEL-APP*. A SATEL-APP object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window.

- Under Propagator leave the *Lokangle* option set and under Element Type choose the *Mean* option. Edit the text boxes that appear so that *Inclination*=98.583, *Arg. of Perigee*=114.661, *Mean Anomaly*=246.292, *Eccentricity*=0.0008, *R.A. Asc. Node*= 19.714, and *Mean Motion* = 14.327 (leave *d(MM)/dt/2*, *d2(MM)/dt2/6*, and *BSTAR* at their default values). Set the orbit reference time by editing the *T_ref* text box to read "11/04/96 19:48:29". Type "LEO" in the *Sat. Name* text box and leave *Time Step (s)* set at 60 seconds. Select the *Run/Update* option in the *Edit* menu and a *Process View* Window will appear as orbit data are generated. Note: Example 2 demonstrates the use of *From File* feature which is not as general but much simpler to use.

- Select the *Graphics* option from the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Satellite*. A Satellite object will be added to the *Active Modules* list and a set of Satellite Options will appear.

- Click on the *Satellite* button and select the option *LEO*, leave the *Data* button set to *No Date*, use the *Label* selector to choose *Sat. Name,* and check *Pop Marker*. Under Reference Frame place a check next to *Inertial (ECI)* and uncheck *Geocentric (GEOC).* Click on in the *Display* box and the LEO satellite will appear in orbit near Antarctica (under India) in the 3D Window.

- Select the *Animate Tool* option in the *Edit* menu and an *Animate* window will appear. Click the *Find Range* button to allow the animator to register the times span covered by the orbit generated. Use the right arrow on the time slider until you reach "11/11/96 06:00" and the 3D Window should resemble the figure below.



- Edit the *Time Step* text box to read “300”, click on the *Update* button, and then click the *Animate* button under the slider and the changing LEO satellite position will be displayed at 300 second intervals. Clicking the *Animate* button again halts the animation. The *Done* button will halt the animation and dismiss the *Animation* Window.

Create and Display an AURORA Science Module data set,

- Select the *Science* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *AURORA* in the *Available Modules* list and a *SciAurora* object will be added to the *Active Modules* list. A set of AURORA Options will appear in the Environment Window.

- Leave all AURORA Options set at the default values. Select the *Run/Update* option in the *Edit* menu and a *Process View* Window appears momentarily. When the model is complete, this window disappears and the *Model Status* box will indicate that the Global Parameters *Day*, *Time*, and *Kp* were used and the “MODEL IS READY AND UP TO DATE.”

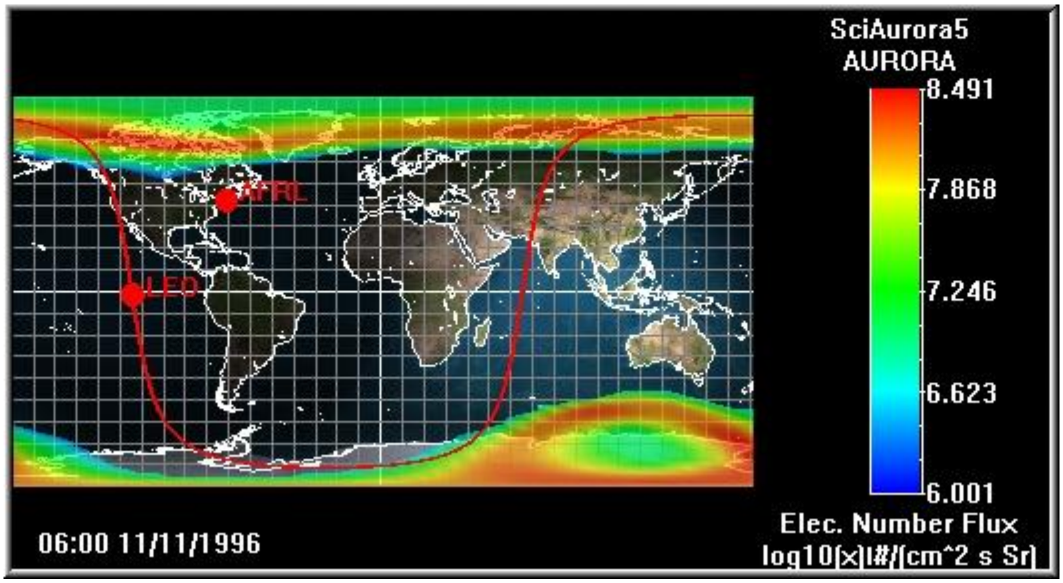
- Select the *Graphics* option in *Module* menu and *Available Modules* and *Active Modules* lists will appear. Scroll up the *Available Modules* list, select *Coord Slice,* and a *Coord Slice* object will be added to the *Active Modules* list. A set of Coord Slice Options will appear in the Environment Window. The Cut Plane options *C0, C1*, and *C2* correspond to the three spherical coordinates used when building the aurora data set. Use the default setting called *C0* to slice the data at a constant radius.

- Click the *Data* button, go to the *SciAurora* option, and select *Elec. Number Flux*. Click in the *Display* box and auroral electron data will appear in the 3D Window. From the *Viewport* menu, use the *Show Color Bar* option to show the color bar with units now representing auroral electron number flux.

- To make the auroral display more transparent, click the *Transparency* button in the Environment Window and move the slider to a value of 0.70. Rotate the Earth and notice that the auroral electron number flux is displayed at both poles. To see more detail on the

continents, highlight the *Earth* entry in the *Active Modules* list on the right and check-off *Textured* in the Outline Detail section of the Earth Options inputs.

- Use the *Viewport* menu to select *Projection* and then its *Two D* option (the *Three D* option will convert it back to a 3D window). To get the AURORA color bar to reappear highlight the *Coord Slice* entry in the *Active Modules* list on the right (or hold down the *Ctrl* key and click the mouse on the colored electron precipitation data in the graphic window). The window should resemble the following figure.



- Use the *Viewport* menu to select *Projection* and then its *Three D* option to transform the view back to 3D.

Create a CRRESELE Science Module data set,

- Select the *Science* option from the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *CRRESELE* in the *Available Modules* list. A *SciCrresEle* object will be added to the *Active Modules* list and a set of CRRESELE Options will appear.

- Click on the *B-Model* button and select *Dip-Tilt-Off*. This is not the magnetic field model originally used to reduce the CRRES data but will suffice for this example. From the *Energy Channel (MeV)* list, select *1.6* MeV and from the *Ap15 Model Range* list, select the *Ap15 20.0 - 25.0* option. Leave the *Compute* button alone.

- Select the *Run/Update* option in the *Edit* menu and a *Process View* Window will appear while CRRESELE is running. When the model is complete that window will disappear and the model inputs will appear in the *Model Status* box at the bottom of the Environment Window with the message "MODEL IS READY AND UP TO DATE."

Display two CRRESELE data coordinate slices at constant longitude,

- Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *Coord Slice* in the *Available Modules* list and a second *Coord Slice* object will be added to the *Active Modules* list. A set of Coord Slice Options will appear in the Environment Window.

- Click the *Data* button and select *Flux* under the *SciCrresEle* option. Select the Cut Plane *C2* to slice the CRRESELE data at a constant longitude. Click on *Display* and CRRESELE data appear near -180 degrees Longitude. Move the *Position Value* slider until the longitude value displayed under the slider is approximately zero.

- Notice that the color bar units now represent CRRESELE electron number flux. In general, the color bar units correspond to the graphics object currently highlighted in the *Active Modules* list and the input options displayed in the Environment window. To quickly regain the color bar corresponding to the aurora data, depress the *Ctrl* key and click the left mouse button on the auroral data. This action will restore the AURORA environment window also.

- Click again on *Coord Slice* in the *Available Modules* list and a third *Coord Slice* object will be added to the *Active Modules* list. A set of Coord Slice options will appear in the Environment Window. Click the *Data* button and select *Flux* under the *SciCrresEle* option. Select the Cut Plane option *C2*, click on *Display*, and CRRESELE data appears again near 180 degrees Longitude. There are now two electron belt coordinate slices on opposite sides of the Earth.

Renaming Like-Named Objects in the Active Modules List,

- To help keep track of which *Active Modules* entry corresponds to which graphic element, AF-GEOSpace contains a renaming feature. This example now has three *Coord Slice* entries in the *Active Modules* list on the right, one for the AURORA and two for CRRES-ELE data. Highlight the first *Coord Slice* entry in the *Active Modules* list, select the *Rename* option in the *Edit* menu and a *Rename Model* window appears. Edit the *Name* text box to read "Aurora" and click *OK* to change the Coord Slice entry's name. Repeat the process with the remaining two *Coord Slice* entries in the *Active Modules* list and rename them "CRRES-ELE1" and "CRRES-ELE2". Because more orbits will be generated below, highlight the *Satellite* entry and rename it "LEO".

Create a CRRESPRO Science Module data set,

- Select the *Science* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *CRRESPRO* in the *Available Modules* list. A *SciCrresPro* object will be added to the *Active Modules* list and a set of CRRESPRO Options will appear.

- Click on the *B-Model* button and select *Dip-Tilt-Off*. Again, this is not the magnetic field model originally used to reduce the CRRES data but will suffice for this example. From the *Energy Channel (MeV)* list select 10.7 MeV and use the *Activity* button to select the *Active* option.

- Select the *Run/Update* option from the *Edit* menu button and a *Process View* Window will appear while CRRESPRO is running. When the model is complete that window will disappear and the model inputs will appear in the *Model Status* box at the bottom of the Environment Window along with the message "MODEL IS READY AND UP TO DATE."

Display two CRRESPRO data coordinate slices at constant longitude,

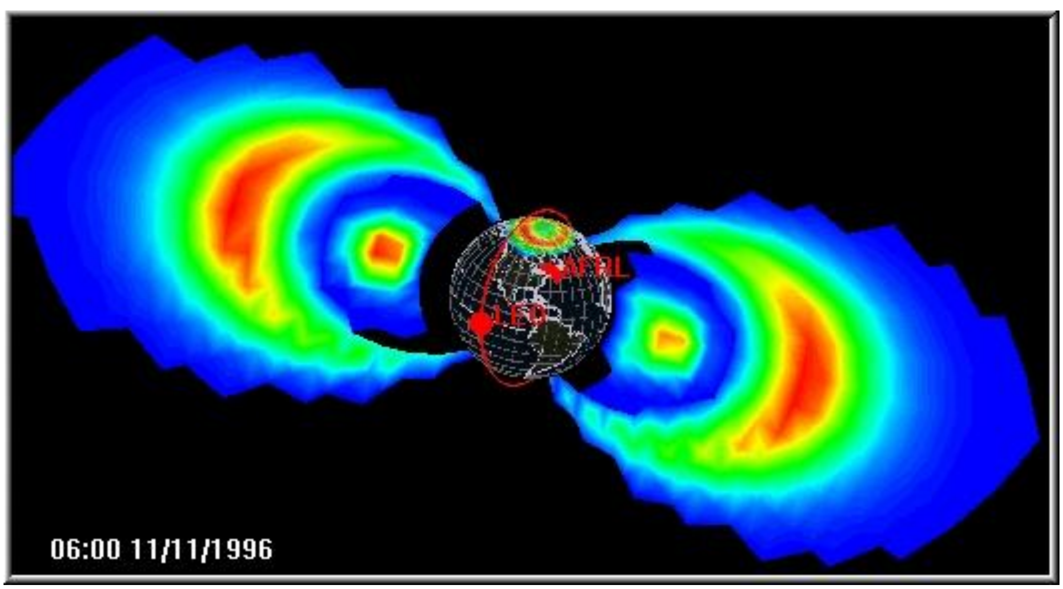
- Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *Coord Slice* in the *Available Modules* list and a *Coord Slice* object will be added to the *Active Modules* list. A set of Coord Slice options will appear in the Environment Window.

- Click the *Data* button and select *Flux* under the *SciCrresPro* option. Select the Cut Plane option *C2* to slice the CRRESPRO data at a constant longitude. Click on *Display* and CRRESPRO data appears near 180 degrees Longitude. The units for the color bar now represent CRRESPRO proton number flux. Select *Rename* from the *Edit* menu and enter "CRRES-PRO1" as the new coordinate slice name.

- Click on *Coord Slice* in the *Available Modules* list and a *Coord Slice* object will be added to the *Active Modules* list under *CRRES-PRO2*. A set of Coord Slice Options will appear in the Environment Window.

- Click the *Data* button and select *Flux* under the SciCrresPro option. Select the "Coordinate" *C2* to slice the data at constant longitude and click on *Display*. CRRESPRO data appears again near 180 degrees Longitude. Move the *Position Value* slider to read approximately 0.5. This places the proton data slice just west of the nearby electron data.

- To make more room for the data displayed, go to the *Viewport* menu and turn off the *Show Color Bar* feature. The figure should now resemble the following figure.



Create and display a Medium Earth Orbit (MEO) data set with a communications link to AFRL,

- Select the *Applications* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *SATEL-APP* in the *Available Modules* list. A second *AppSatel* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window.

- Under Propagator leave *Lokangle* selected and under Element Type choose the option *Mean*. Edit the text boxes that appear so that *Inclination*=55.057, *Arg. of Perigee* = 203.685, *Mean Anomaly*=156.036, *Eccentricity*=0.007, *R.A. Asc. Node*=314.183, and *Mean Motion* = 2.006 (leave *d(MM)/dt/2, d2(MM)/dt2/6*, and *BSTAR* at their default values. Edit the orbit reference time so that the *T_ref* text box reads "11/04/96 08:44:20". Type "MEO" in the *Sat. Name* text box and leave *Time Step(s)* set at 60. Use the *Edit* menu to *Rename* this application entry "MEO".

- Select the *Run/Update* option in the *Edit* menu and a *Process View* Window will appear as orbit data are generated. Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and click on *Satellite*. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear in the Environment Window.

- Use the *Satellite* button to select *MEO*, leave *Data* set to *off*, use the *Label* button to select *Sat. Name*, and check *Pop Marker*. Under Reference Frame, check *Inertial (ECI)* and uncheck *Geocentric (GEOC).* Click in the *Display* box and the MEO orbit will appear in the 3D Window. Use the *Edit* menu to *Rename* the Satellite entry as "MEO"

- Scroll down the *Available Modules* list and select *Link*. A *Link* object will appear in the *Active Modules* list and Link options will appear in the Environment Window. Highlight the *AFRL* entry in one of the *Station* lists and highlight *MEO* in the other Station list. Click the *Display* box to create the line-of-sight link connecting AFRL to the MEO satellite.

- If AFRL and the MEO satellite are not within line-of-sight of each other, select the *Animate Tool* in the *Edit* menu to use the *Animate* Window. Move the slider in the *Animate* window until you will notice that the link line will appear only when the MEO satellite is within line-of-sight of AFRL. Click on the *Done* button to retire the *Animate* window.

Create and display a High Earth Orbit (HEO) data set with a downward looking detector cone,

- Select the *Applications* option from the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *SATEL-APP* in the *Available Modules* list. An *AppSatel* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window.

- Under Propagator leave the *Lokangle* option selected and choose *Mean* under Element Type. Edit the text boxes that appear so that *Inclination*=86.302, *Arg. of Perigee*= 278.085, *Mean Anomaly*=22.234, *Eccentricity*=0.6338*, R.A. Asc. Node*=24.922, and *Mean Motion* = 1.362 (leave *d(MM)/dt/2, d2(MM)/dt2/6*, and *BSTAR* at their default values). Adjust the orbit

reference time by editing the *T_ref* text box to read “10/29/96 17:06:38”. Type “HEO” in the *Sat. Name* text box and leave *Time Step(s)* = 60. Use the *Edit* menu to *Rename* this entry “HEO”.

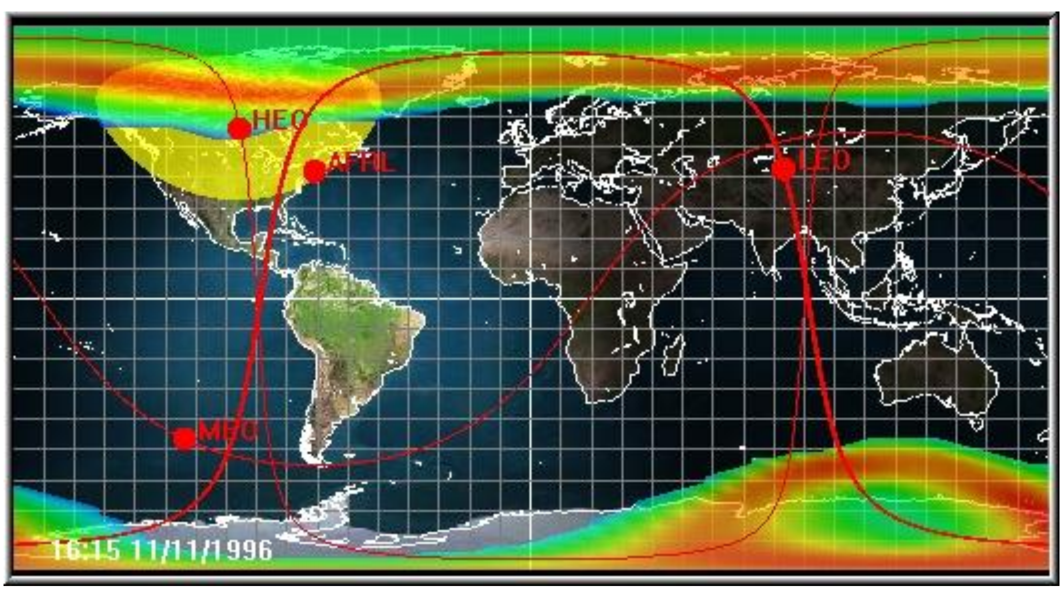
- Select the *Run/Update* option in the *Edit* menu and a *Process View* window will appear, then vanish and the *Model Status* box will say the “MODEL IS READY AND UP TO DATE.”

- Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Scroll down and click on *Satellite* in the *Available Modules* list. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear.

- Select *HEO* with the *Satellite* button, leave the *Data* button set to *off*, use the *Label* button to select *Sat. Name*, and check *Pop Marker*. Under Reference Frame check *Inertial (ECI)* and uncheck *Geocentric (GEOC)*. Use the *Edit* menu to *Rename* the Satellite entry as “HEO”

- Scroll up in the *Available Modules* list and select *Detector*. A *Detector* object will appear in the *Active Modules* list and Detector option will appear in the Environment Window. Highlight the *HEO* entry in the *Origin Station* list by clicking on it. Move the *View Angle* slider (or edit the text box) until the angle equals 7 degrees. Click on *Display* and the detector cone should appear coming from the HEO satellite. Click the *Transparency* button and move the slider that appears to a value of 0.70 to make the cone slightly transparent. As with the Link visualized above, you can open the *Animate Tool* in the *Edit* menu and move the *Animate Window* slider around to see the detector cone at different positions.

- A better picture of the detector’s footprint can be viewed by simply changing the dimensionality of the active 3D window. Open the *Viewport* menu and slide down to the *Projection* item and select the *Two D* option. Again, the *Animate Tool* in the *Edit* menu can be used to see how the detector visualization changes with time. Note that the detector footprint in 2D can breakup near the poles. Move the *Animate Window* time slider to read “11/11/96 16:15” and the 2D display should resemble the next figure. Switch back to 3D



with the *Viewport* menu by selecting *Projection* and then *Three D*.

Create and display a Geosynchronous Orbit (GEO) data set with a detector cone,

- Select the *Applications* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *SATEL-APP* in the *Available Modules* list. An *AppSatel* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window.

- Under Propagator leave *Lokangle* selected and choose *Mean* under Element Type. Edit the text boxes that appear so that *Inclination*=0.1233, *Arg. of Perigee*=332.651, *Mean Anomaly*=263.618, *Eccentricity*=0.0004, *R.A. Asc. Node*=266.253, and *Mean Motion* = 1.003 (leave *d(MM)/dt/2, d2(MM)/dt2/6*, and *BSTAR* at their default values). Edit the orbit reference time so that the *T_ref* text box reads "11/04/96 15:31:55". Type "GEO" in the *Sat. Name* text box and leave *Time Step(s)* set at 60 seconds. Use the *Edit* menu to *Rename* this application entry "GEO".

- Select the *Run/Update* option in the *Edit* menu and a *Process View* Window appears briefly and the *Model Status* box will indicate "MODEL IS READY AND UP TO DATE."

- Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *Satellite* in the *Available Modules* list and a *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear in the Environment Window.

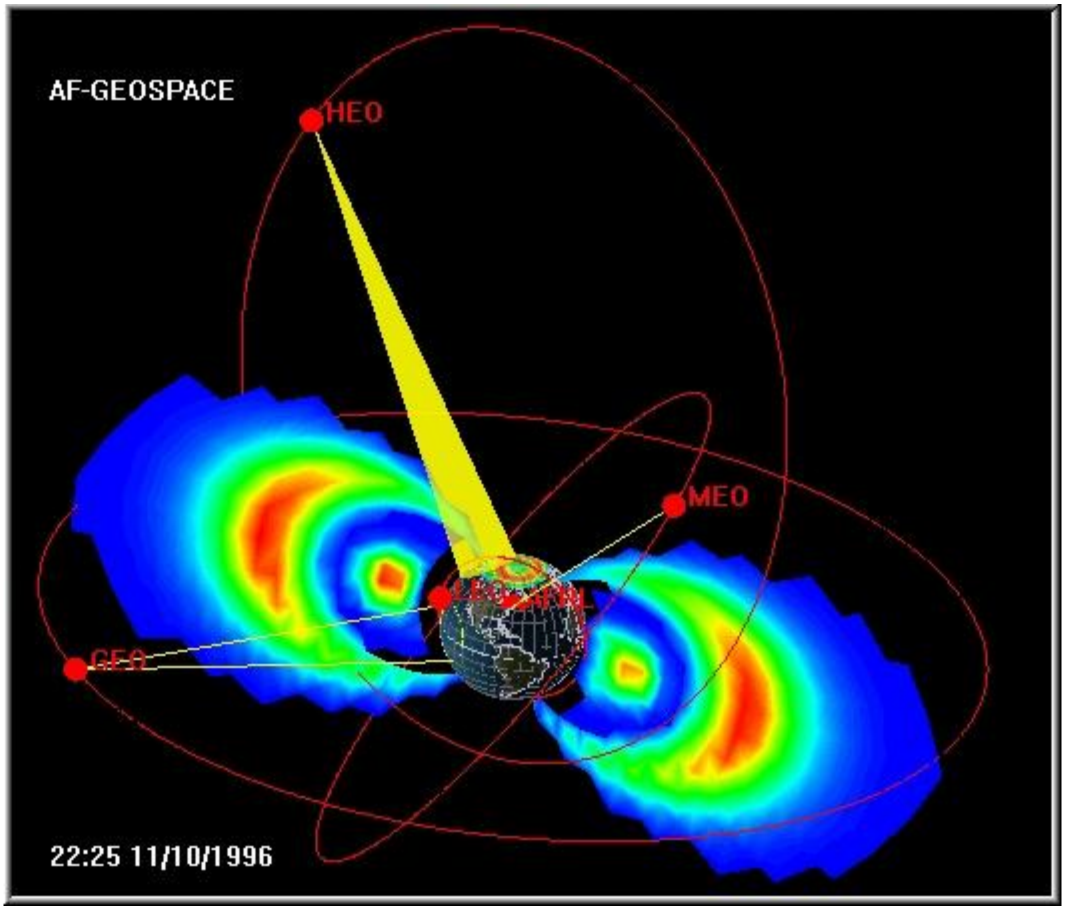
- Use the *Satellite* button to select *GEO*, leave the *Data* button set to *No Date,* use the *Label* button to select *Sat. Name*, and check *Pop Marker*. Under Reference Frame check *Inertial (ECI)* and uncheck *Geocentric (GEOC)*. Click the *Display* box and the GEO orbit will appear over the Pacific Ocean in the 3D Window. For completeness, use the *Edit* menu to *Rename* this graphic entry "GEO".

- To associate a detector cone with the GEO satellite, scroll up in the *Available Modules* list and select *Detector*. A second *Detector* object will appear in the *Active Modules* list and Detector option will appear in the Environment Window. Scroll down the *Origin Station* list and highlight the *GEO* entry by clicking on it. Move the *View Angle* slider (or edit the text box) until the angle equals 8 degrees. Click on *Display* and the detector cone should appear coming from the HEO satellite. Uncheck the *Solid* box to produce a wire frame rendering of the detector.

Display an Annotation Label in the Active Graphic Window,

- Select the *Graphics* option in the *Modules* menu and *Available Modules* and *Active Modules* lists will appear. Select *Annotation* from the *Available Modules* list. An Annotation object will be added to the *Active Modules* list and a set of Annotation Options will appear in the bottom of the Environment Window.

- Edit the *Text* field to read "AF-GEOSPACE" and click *Display* and the label will appear in the far lower left corner of the graphic window. Move the *X Position* slider to 0.04 and the *Y Position* sliders to approximately 0.90 to place it in the upper left of the graphic window.



- Move the *Animate Window* time slider to read "11/10/96 22:25" and the 3D display should resemble the figure above.

While the HEO detector is scanning the aurora over Alaska, the MEO satellite is entering the heart of the 1.6 MeV electron radiation belt and is in line-of-sight of AFRL. The LEO satellite is moving southward over equator in the Pacific while the GEO satellite detector is still monitoring a nearby patch of open water.

This completes the Example of Space Particle Hazards.

2) Low Earth Orbit Particle Environment

This example demonstrates the use of the CRRES proton (CRRESPRO) and the CRRES electron (CRRESELE) radiation belt flux Science Modules, the DMSP Aurora Science Module (AURORA), the Satellite Application Module (SATEL-APP), and a variety of graphical tools.

Goal: Demonstrate the spatial distribution of the particle populations encountered by the Defense Meteorological Satellite Program (DMSP) satellite (in a low Earth orbit), including the low altitude projections of the inner and outer radiation belts as well as the auroral oval. It will be shown that the inner belt protons penetrate to DMSP altitude in a localized region above the South Atlantic (South Atlantic Anomaly) due to the asymmetry of the Earth's magnetic field. A low altitude projection of the outer radiation belt electrons appears in both hemispheres and the particle flux from the magnetosphere's plasma sheet precipitates into the ionosphere forming the high latitude auroral oval. Both 2D and 3D representations of these populations, along with a trace of a DMSP orbit, will be shown juxtaposed over the Earth. 1D flux plots versus time will also be generated for each of the three populations.

Procedure Summary: Section 1 starts a Static Model session, Sections 2-4 generate the CRRESPRO, CRRESELE, and AURORA Science Module data sets, Section 5 generates the DMSP orbit data set, Section 6 creates a 2D and a 3D view of the Earth with a superimposed DMSP orbit, Section 7 creates a 2D view of the particle environment, Section 8 creates a 3D view of the particle environment, and Section 9 creates a 1D plot of flux vs. time for the DMSP orbit.

1) Start an AF-GEOSpace session and set global input parameters,

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this run, set the date and time by editing the Globals text boxes to read: *Start:Year* = 1997, *Day* = 200, and *UT* = 10:30 (Day 200 = 19 July). Click on the *Archive* option of the *Globals* button and the values of the Kp geomagnetic index, sunspot number (SSN), F10.7 cm radio flux, and the Ap geomagnetic index that have been archived by NGDC will be retrieved for the appropriate time (*Kp*=1.7, *SSN*=0, *F10.7*=72.8, and *Ap*=6).

2) Create a CRRESPRO Science Module (inner proton belt) data set,

- Choose *Module* from the Environment Window Menu Bar and select *Science* from the options. *Available Modules* and *Active Modules* lists will appear. Click on *CRRESPRO* in the *Available Modules* list. A *SciCrresPro* object will be added to the *Active Modules* list and a set of CRRESPRO Options will appear in the Environment Window.

- Scroll down the *Energy Channel (MeV)* list select the 47.0 MeV channel.

- Click on the *B-Model* button and select the *IGRF85* option to generate a realistically positioned South Atlantic Anomaly (SAA) for Low Earth Orbit (LEO) altitudes relatively quickly. Note that the *IGRF85/O-P* model was used to construct CRRESPRO but take longer to run. Also, while the offset-tilted dipole option *Dip-Tilt-Off* is fastest, it does not yield a realistically positioned SAA. Leave the *Activity* button set to the *Quiet* model option. The *Quiet* model contains only the primary inner belt and is more typical of the inner magnetosphere. The *Active* model was constructed from CRRES data following the 24 March 1991 magnetic storm and contains the second proton belt.

- Select the *Grid Tool* option in the *Edit* menu and the *Grid Tool* window will appear. Leave unchanged the default grid Spacing, Geometry, and coordinate System in order to generate a linearly spaced spherical grid defined by radius, geocentric latitude, and geocentric longitude. Increase all three *Npoint* text boxes from values of 20 to 40. In the Rad, GEOC (Re) section set *Min*=1.0 and *Max*=3.0. Close the *Grid Tool* Window by clicking the *OK* button.

- Select the *Run/Update* option in the *Edit* menu. A *Process View* Window will appear while CRRESPRO is running and then disappear. Identification and status of the model will appear in the *Model Status* box in the lower part of the window.

3) Create a CRRESELE Science Module (outer electron radiation belt) data set,

- Click on *CRRESELE* in the *Available Modules* list. A *SciCrresEle* object will be added to the *Active Modules* list and a set of CRRESELE Options will appear. From the *Energy Channel (MeV)* list select the 1.6 MeV channel. Click on the *B-Model* button and select the *IGRF85* model as was done for CRRESPRO. From the *Ap15 Model Range* list, choose *Ap15 7.5 - 10.0* to approximate the global value of 7.56 (shown below the *Compute* button) which was determined for day 200/1997. This will select a model constructed from CRRES data during those time intervals when the average value of daily Ap over the preceding 15 days was between 7.5 and 10.

- Select the *Grid Tool* option in the *Edit* menu and the *Grid Tool* window will appear. Under Rad, GEOC (Re) set *Npoint*=60, *Min*=1.0, and *Max*=7.0. Under Lat, GEOC (Deg N) set Npoint=60, *Min*= -85, and *Max*=75. Under Lon, GEOC (Deg E) set *Npoint*=40, *Min*= -180, and *Max*=180. Close the *Grid Tool* window by clicking the *OK* button.

- Select the *Run/Update* option in the *Edit* menu and a *Process View* window will appear while CRRESELE is running. When the model is complete the window will disappear and the identification and status of the model will appear in the *Model Status*.

4) Create an AURORA Science Module data set,

- Click on *AURORA* in the *Available Modules* list and a *SciAurora* object will be added to the *Active Modules* list. Within the set of AURORA Options appearing in the Environment Window, select the *Fast IGRF* option under Internal B-Field and leave all other settings unchanged.

- Select the *Grid Tool* option in the *Edit* menu. The default is a two-dimensional latitude-longitude grid at a constant radius of 1.0173 Earth radii. This is the original domain on which the aurora model was constructed. Under Rad, GEOC (Re) set *Npoint*=2, leave *Min*=1.0173, and reset *Max*=1.14 Re to bracket the DMSP altitude of 840 km (1.1318 Re). Set *Npoint* equal to 80 in the Lat, GEOC (Deg N) and Lon, GEOC (Deg E) sections. Close the *Grid Tool* window by clicking on the *OK* button.

- Select the *Run/Update* option in the *Edit* menu. When the model is complete the Process View window will disappear and the *Model Status* box will be updated indicate that the Global Parameters *Day*, *Time*, and *Kp* are being used to construct the model.

5) Create the DMSP orbit data set,

- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *SATEL-APP* (satellite application). An *AppSatel* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window.

- With the *From File* Element Type selected, click on the *File* button and a window appears showing the contents of the folder $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled "dmsp.txt" and click the *Open* button.

- A list of DMSP satellites will appear in the *Current Element File* list in the middle of the window. Select *DMSP F14* and the satellite name and the reference time associated with the orbital elements are given in boxes below the list box. To view the orbital elements for any satellite loaded using the *From File* option, click on the *Mean* element type button. Reselect the *From File* element type button to return to the previous view. The default value for the start time (*T_start*) is taken from the global values at the top of the Environment Window. Whenever a SATEL-APP module is run in "static" mode, a 1-day interval with a 60-second time step is used by default.

- Edit the *T_start* text box to read "07/19/97 08:30:00" and edit the *T_stop* text box to read "07/19/97 12:30:00". Select the *Run/Update* option in the *Edit* menu to create the orbit data set. When completed, the *Model Status* box will indicate that the "MODEL IS READY AND UP TO DATE."

6) Create 2D and 3D views of Earth with an orbit trace,

- Select the *Create 2D Viewport* option in the *Window* menu and a 2D window will be created. The *Window* menu options labeled *1:1* (the default 3D viewport) and *2:2* (the 2D viewport just created) can be used to bring the windows to the front. Use the *Tile* option in the *Window* menu to make both windows viewable.

- Select the *Graphics* option from the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Select *Earth* from the *Available Modules* list. An *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear in the Environment Window. Select Outline Detail options *Textured* and *Geographic Bndys*. Click on *Display*

and the Earth will appear in the active 2D window. To place the Earth in the 3D window, simply click on that window to activate it and select *Display* again.

- Scroll down the *Available Modules* list and select *Satellite*. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear. Click the *Satellite* list and choose *DMSP F14*. Click *Display* to place the orbit in the active window. To place the orbit in the other window, simply click on that window and select *Display* again.

- Click on the *Label* button and select the *Rad, Lat, Lon* option. Radius (1.13 Re), latitude (-81.14), and longitude (-119.94°) will be displayed at the current satellite position (solid red circle). Click the *Label* button and select *Time*. The coordinate label will be replaced by the day of year/time. After clicking in the 3D window to ensure it is active, uncheck the *Show Color Bar* option in the *Viewport* menu to remove the color bars from the graphics windows. The 3D window should resemble the following figure.

- To move the satellite along its orbit, select the *Animate Tool* option in the *Edit* menu and an *Animate* window will appear. The *Time Start* and *Time End* text field values in the *Animate* window key off the global start time. Edit these two windows to match the start and stop times entered in the SATEL-APP module, i.e., 07/19/97 08:30 and 07/19/97 10:30. Now reset the *Time Step* field to 60 seconds and click the *Update* button. Moving the slider until it reads 07/19/97 10:12 to position DMSP14 over the South Atlantic Anomaly (SAA) at "r"=1.14, "lat"= -29.80°, "lon"= -29.99°. To move the satellite in 60-second increments, use the left/right arrow buttons located at the slider ends. Note that while the *Animate* box under the slider is checked, the satellite will move continuously using the designated *Time Step*. Click the *Done* button to remove the *Animate* window (it will retain the current settings).

7) View of the inner proton radiation belt, the outer electron radiation belt, and the auroral oval at the DMSP altitude,

- CRRESPRO - Scroll up the *Available Modules* list and select *Orbit Slice*. An *OrbitSlice* object will be added to the *Active Modules* list and a set of Orbit Slice Options will appear.

- Use the *Satellite* selector to pick *DMSPF14*. Click the *Data* button and select *Flux* under the *SciCrresPro* option. The coordinate parameters *P0, P1*, and *P2* correspond to the three

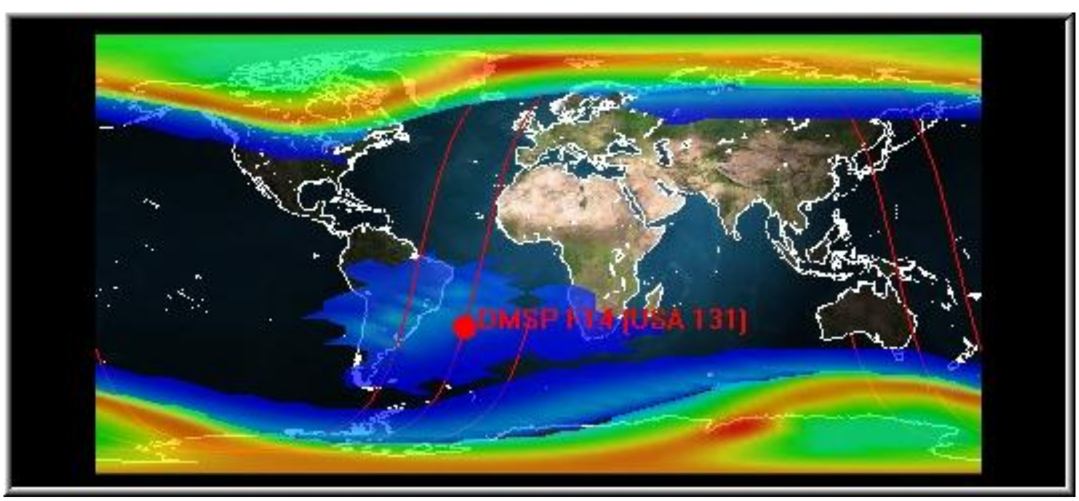
coordinates that are set by the *Grid Tool* in the appropriate Science Module (for this example they represent geocentric radius, latitude, and longitude). Select *P0* to produce a slice of flux values at constant radius. Select *Display* to place the orbit slice in the active window.

- Click in the window that does not have proton data showing, and click *Display* once more to place the coordinate slice in the other window. At DMSP altitude the inner belt appears as a relatively localized area centered near 304^{o} E longitude and -30^{o} latitude.

- The transparency of the CRRESPRO Orbit Slice can be changed by clicking on the *Transparency* button at the right side of the Orbit Slice Options section. A *Transparency* slider will be displayed at the bottom of the window. Changing the slider value of 0.70 so the continent outlines can be seen. At this altitude, it should be apparent that a maximum in flux intensity appears near the east coast of South America. This feature is referred to as the South Atlantic Anomaly (SAA).

- CRRESELE – Select *Orbit Slice* again in the *Available Modules* list on the left. Another *OrbitSlice* object will be added to the *Active Modules* list and a set of Orbit Slice options will appear. Use the *Satellite* selector to pick *DMSPF14*. Click the *Data* button and select *Flux* under the *SciCrresEle* option. Select *P0* to produce a slice of flux values at constant radius. Select *Display* to place the orbit slice in the active window. Click in the window that does not have electron data showing, and click *Display* once more to place the coordinate slice in the other window. Use the *Transparency* feature to set a Transparency value of 0.70.

- AURORA - Select *Orbit Slice* again in the *Available Modules* list on the left. Another *OrbitSlice* object will be added to the *Active Modules* list and a set of Orbit Slice Options will appear. Use the *Satellite* selector to pick *DMSPF14*. Click the *Data* button and select *Ion Number Flux* under the *SciAurora* option. Select *P0* to produce a slice of flux values at constant radius. Select *Display* to place the orbit slice in the active window. Click in the window that does not have aurora data showing, and click *Display* once more to place the coordinate slice in the other window. Use the *Transparency* feature to set a Transparency value of 0.70. With the 2D window active, uncheck the Show *Color Bar* option listed in the *Viewport* menu and the 2D graphic window should resemble the following figure.



8) Create constant longitude 3D views of the inner proton radiation belt and the outer electron radiation belt,

- Scroll up the *Available Modules* list and click on *Coord Slice*. A *Coord Slice* Object will be added to the *Active Modules* list and a set of Coord Slice Options will appear.

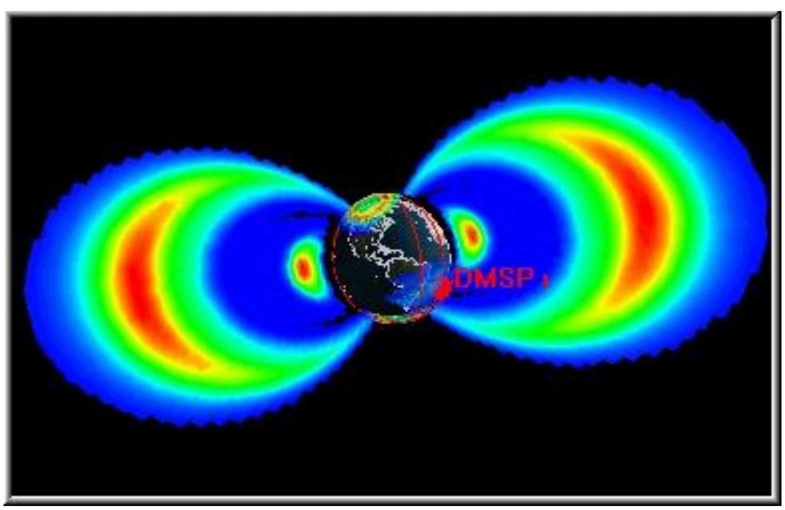
- Click the *Data* button and select *Flux* under the *SciCrresPro* option. Under Cut Plane, select the *C2* option. Click in the 3D window to make it active and select *Display* to place a coordinate slice at a constant longitude in the 3D window. You may need to use the left mouse button to rotate the Earth to see the coordinate slice.

- Return to *Available Modules* and click on *Coord Slice*. A second *Coord Slice* Object will be added to the *Active Modules* list and a new set of Coord Slice Options will appear.

- Click the *Data* button and select the *Flux* under the *SciCrresEle* option. Under Cut Plane select the *C2* option and click *Display* to place cross-section of the outer electron belt from the CRRESELE model in the 3D Window.

- Repeat the first 4 steps in this Section 8 to generate a second cross-section of the inner proton and outer electron belts. In each of these two new cross-sections, move the *Position Value* slider under Coord Slice Options to ~0.5 so that the longitude slice is diametrically opposed (at 180^{o}) to the two original cross-sections.

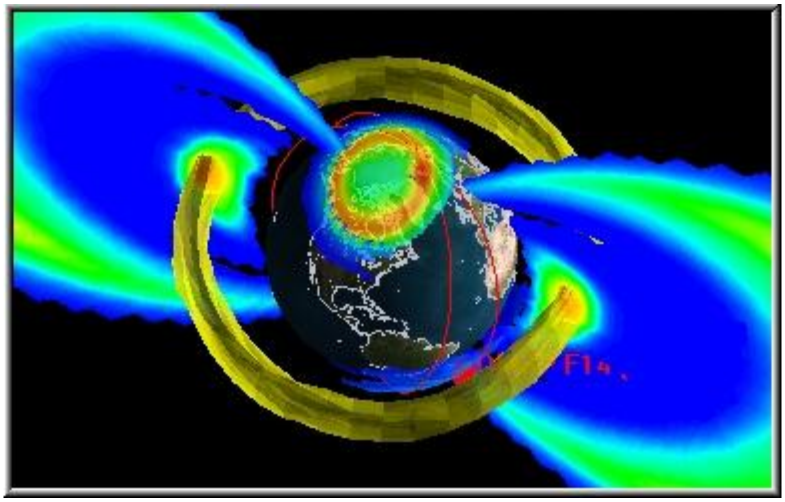
- The image in the 3D Window can be rotated/scaled by using the left/right mouse button when the pointer is in the 3D Window. Use the mouse controls to arrange the Earth in the 3D Window so it resembles the following figure.



- Scroll down the Available Modules list and select *Isocontour* and an *Isocontour* object will be added to the *Active Modules* list and a set of Isocontour options will appear.

- Use the *Data* button to select *SciCrresPro* and the *Flux* option. Click *Display* and a green Isocontour will appear representing the proton belt. Move the *Contour Value* slider to a value

of 0.75 and use *Transparency* and set the *Transparency* slider to 0.70. A view from the higher northern latitudes should resemble the following figure.



9) A one-dimensional plot of the CRRESPRO proton flux, CRRESELE electron flux, and AURORA ion number flux as seen by the DMSP satellite can be generated as follows,

- Return to the *Window* menu of the Environment Window and select *Create 1D Viewport*. An empty 1D Window with a white lined frame will appear and fill the graphics window area. This new 1D menu is represented by the new *3:3* entry in the *Window* menu.

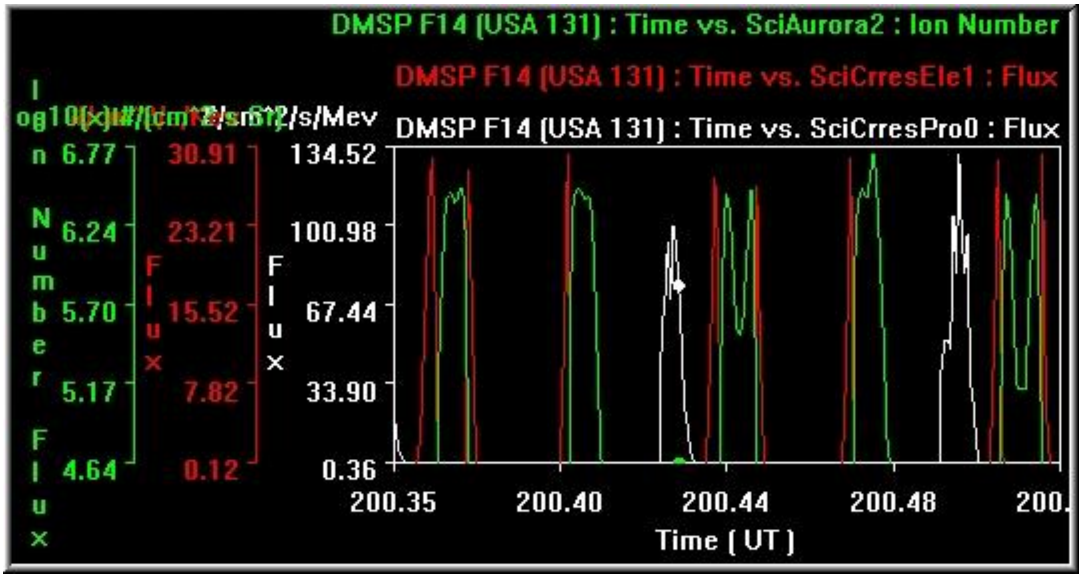
- Scroll down the *Available Modules* list and select *Orbit Probe*. An *Orbit Probe* Object will be added to the *Active Modules* list and a set of Orbit Probe Options will appear.

- Click on the *Path/Abscissa* button and select the *Time* option under *AppSatel* (this represents the *DMSP F14* satellite. Click on the *Data/Ordinate* button and select the *Flux* option under *SciCrresPro*. Click on *Display* and a Flux vs. Time along the DMSP orbit will appear.

- Repeat the last 2 steps, replacing *SciCrresEle* for *SciCrresPro*. Now, repeat those same 2 steps once again but select *Ion Number Flux* under *SciAurora* instead of *Flux* under *SciCrresPro*.

- Since the time scale (x-axis) is the same for all flux curves, two of the three may be deleted to avoid redundancy. To do this, uncheck the Enabled option in the X Axis section. Now highlight a different *Orbit Probe* object under the *Active Modules* list (not the *Available Modules* list!). Repeat the above procedure to delete a second x-axis. The 1D Window should resemble the final figure below.

This 1D figure and the 2D figure produced earlier illustrate how DMSP can be exposed, in turn, to auroral (green), proton belt (white), and electron belt (red) fluxes. Select *Animate Tool* from the *Edit* menu and start the Animation. If you view the 1-D (follow the colored dots showing the current flux) and 2-D (follow the satellite marker) plots together you can see the correspondence between them.



This completes the Example of the Low Earth Orbit Particle Environment.

3) The Earth's Magnetic Field: Placement of the Current Sheet (Dynamic)

The following dynamic example demonstrates the use of the magnetic field BFIELD-APP Module, the COORDSLICE and FIELD-LINES Graphics Module, Animation, and a variety of other visualization tools.

Goal: The solar wind interacts with the Earth's intrinsic magnetic field to form a magnetic cavity called the magnetosphere. Solar wind pressure (from particles and magnetic field) compresses the magnetosphere on the dayside and helps to form an extended magnetotail of several hundred Earth radii in length on the nightside. The overall interaction results in a sheet of westward traveling current on the nightside that separates a region of anti-sunward directed field lines from a region of sunward directed field lines, i.e., magnetic field lines emanate from the south pole and extend down the magnetotail before passing up through the cross-tail current sheet and returning to Earth to connect at the north pole. In addition, the placement of the cross-tail current sheet (where the magnetic field lines change polarity) changes as a function of Earth's dipole tilt angle relative to the solar direction. The goal of this example is to examine the motion of the current sheet and the magnetic field lines near the midnight meridian during a period when the dipole tilt angle is large.

Start a dynamic AF-GEOSpace session and set global input parameters,

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- Establish a dynamic session by placing a check mark in the small box to the right of the *Start: UT* text field to activate the *End: Year, Day, UT* text fields. For this example, we will select a time period with large dipole tilt angles. Edit the *Start* text fields so that *Year* = 1989, *Day* = 160, and *UT* = 03:00. Edit the *End* text fields so that *Year* = 1989, *Day* = 161, and *UT* = 03:00. From the *Globals:* selector options (on the same bar as the time inputs) pick *Archive* to automatically load parameters from the NGDC archive. Note that the only global parameters affecting the magnetic field configurations are the Day, UT, and Kp.

- View the global parameters for the interval selected using the *Globals* menu (between the *Viewport* and *Help* menus at the very top of the environment window) and selecting the *Show* option. Scroll down the *Globals* text window that appears and notice that the geomagnetic activity index Kp ranges from 2.3 to 5.7 during the interval selected. Dismiss the *Globals* text window using the *Save* or *Cancel* buttons at the bottom.

Display the Earth, Solar Magnetic Axes, Sun Vector,

- Select the *Graphics* option in the *Modules* menu and *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Earth* and an *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear in the bottom of the Environment Window.

- Under Outline Detail select the *Textured* and *Geographic Bndys* options. Under Grid Options select the *Lat/Lon Grid* option. Click in the *Display* box to place the Earth in the default 3D window. The left and right mouse buttons can be used to rotate and scale the Earth image while the cursor is in the Window.

- Select *Axes* from the *Available Modules* list and an *Axes* object will be added to the *Active Modules* list. Change the Axes Frame selection from the default *GEOC* to *SM* and also select the *Sun Vector* option. The Solar Magnetic (SM) coordinate system is useful because the Earth's magnetic dipole is aligned with the SM z-axis (see the Grid Tool section of the documentation for coordinate system definitions) and we would like to view the magnetic field on the nightside. Click the *Display* box and a set of orthogonal axes in the SM coordinate system (red, green, blue) will appear. Notice that the North magnetic pole (blue axis) is located about 11 degrees from the geographic North Pole near Greenland. The yellow axis is the sun vector.

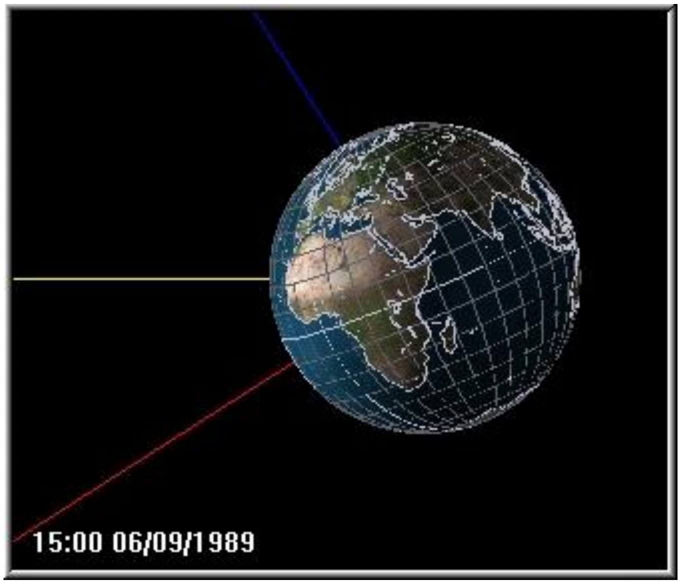
- From the *Viewport* menu, remove the check mark next to the *Show Color Bar* option.

Display a Time/Date Label and Animate in the GSM View Position,

- From the *Viewport* menu, select *View Position* and then the *GSM* option. This will keep the 3-D graphics window fixed in the GSM frame during animation, i.e., the Earth will rotate and the sun vector will remain fixed. From the *Viewport* menu, remove the check mark from the *Perspective* setting. Use the left mouse button to orient the Earth such that the sun vector (yellow) points to the left and the SM y-axis (green) points directly out of the screen.

- To display a time label in the graphics window, select *Annotation* from the top of the *Available Modules* list and an *Annotation* object will be added to the *Active Modules* list. A set of Annotation Options will appear in the Environment Window. Place a check mark in the *Show Date* box and click *Display* and a time/date label will appear in the far lower left corner of the graphic window. Move the *X Position* and *Y Position* sliders to a value of approximately 0.04 to make them easier to read.

- To view the rotation of the Earth and motion of the SM coordinate axes, select the *Animate Tool* option in the *Edit* menu and an *Animate* window will appear. Reset the *Time Step (sec)* text field to match the dynamic step we plan to use, i.e., 10800 seconds, and click the *Update* button. Click the right arrow on the time slider to advance time at 10800-second steps and the 3-D graphic will update automatically. Notice that the sun vector (yellow) and SM y-axis remain fixed in the GSM view position while the SM x-axis (red) remains below the sun vector for the entire day. Set the time slider to 15:00 06/09/1989 using the slider arrows. The graphic should resemble the following figure. Click the *Done* button to close the *Animate* window.



Generate Magnetic Field Data,

- Choose *Module* from the Menu Bar and select *Applications* from the options. *Available Modules* and *Active Modules* lists will appear. Select *BFIELD-APP* from the *Available Modules* list. A BFIELD-APP object will appear in the *Active Modules* list and options for B-Field Application Parameters will appear in the Environment Window.

- Under Generate select the *Gridded Data* and *MLT Field Lines* options and remove the check mark from *MLAT Field Line*. Leave the Internal B-Field option set as *Centered Dipole* and pick the External B-Field option *Tsyganenko '89*. When the *Tsyganenko '89* Window appears leave the *Kp Only* option selected and close the window using the OK button.

- To view field lines in or near a meridian they must originate from a constant Magnetic Local Time (MLT). Set the MLT Field Line Inputs to *MLT*=0, *MLAT0*=65, *MLAT1*=85, and *Steps*=10. With these settings, field lines from local midnight will be separated by 2-degree increments between 65 and 85 degrees latitude.

- The near-Earth portion of the magnetic field resembles a dipole field centered about the Solar Magnetic (SM) z-axis. On the nightside of the magnetosphere, the geomagnetic tail aligns itself along the Earth-Sun direction, i.e., with the sun vector. To track the motion of the magnetic field minimum (the approximate location of the cross-tail current sheet) we will calculate field quantities in SM coordinates. To set up a 3D grid in this coordinate system, select the *Grid Tool* option in the *Edit* menu. At the top of the *Grid Tool* window that appears, select Spacing = *Linear*, Geometry = *Cartesian* and System = *SM* and the coordinates listed will change to X, Y, and Z, SM (Re). To form a grid box on the nightside of the Earth: (1) set X, SM (Re) *NPoint*=20, *Min*= -30, and *Max*= -10, (2) set Y, SM (Re) *NPoints*=10, *Min*= -5, and *Max*=5, and (3) set Z, SM (Re) *NPoints*=20, *Min*= -10, and *Max*=10. Click the *OK* button to close the *Grid Tool* Window.

- Select the *Dynamic Tool* option in the *Edit* menu and a *Dynamic Tool* option window will appear. Place a check mark in the boxes next to the Variables *Bx, By, Bz, |B|,* and *MLT Lines* noted at the top. Edit the *Time Step (sec)* text field to read 10800 seconds and click the *Update List* button. These settings indicate which available BFIELD-APP output variables will be calculated during the Start/End period at intervals of 3 hours (10800 sec). Click the *Done* button to register your selections and dismiss the *Dynamic Tool* window.

- Select the *Run/Update* option in the *Edit* menu to start the calculation of the MLT field line traces and the gridded data set. A *Process View* window appears briefly. When complete, the *Model Status* box lists the dipole tilt angles and the Kp used.

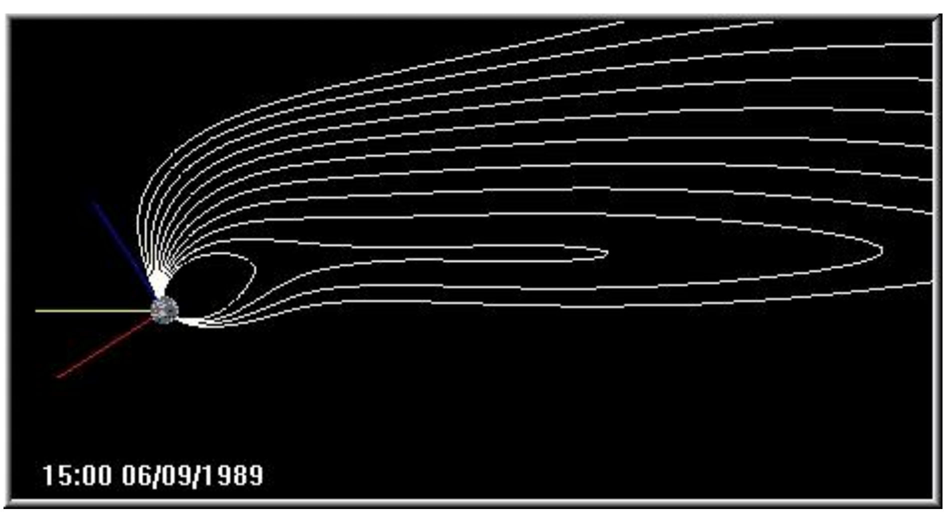
Display Dynamic Sequence of Magnetic Field Lines in 3-D,

- Choose *Module* from the Menu Bar and select *Graphics* from the options. *Available Modules* and *Active Modules* lists will appear. To display magnetic field lines, select *Field Lines* from the *Available Modules* list. A *Fieldlines* object appears in the *Active Modules* list and a set of Field-Lines Options appears in the Environment Window.

- Click on the *Data* button, go down to *AppBfield* and choose *Field Lines-MLT*. Leave *Field Lines* selected as the Plot Type and click *Display*. Click on the *Color* button and click on the center of the color wheel so that the field lines become white.

- Use the mouse buttons while the cursor is in the 3D Window to rotate and rescale the image. By increasing the viewing distance we see that some of the field lines close in the southern hemisphere while the higher latitude magnetic lines are open and extend well beyond our view. Owing to model symmetry, the midnight field lines are coplanar.

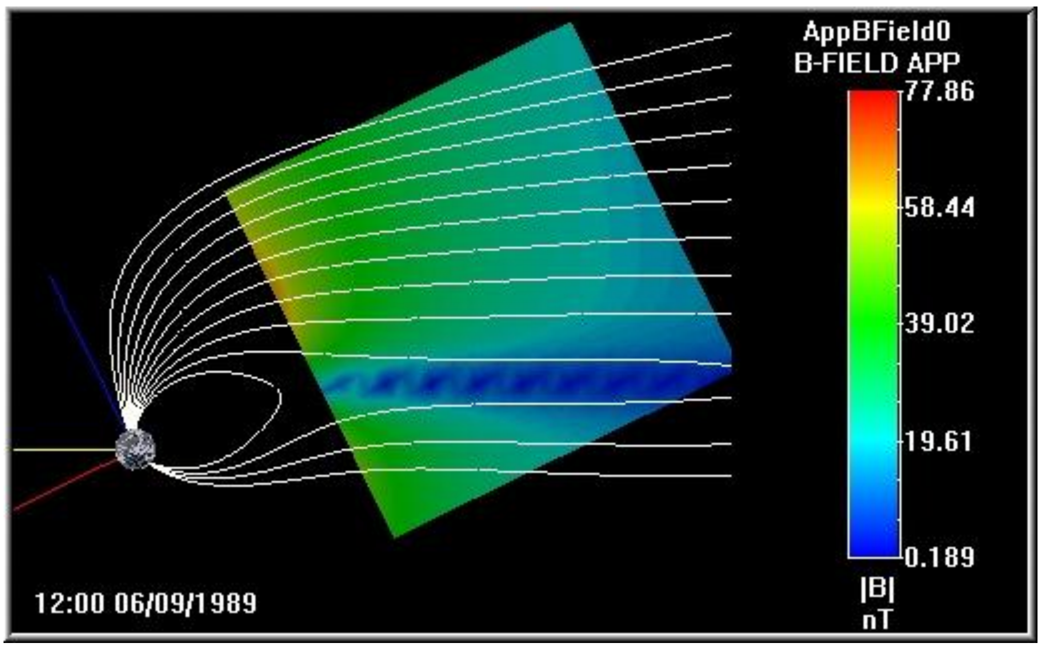
- Open the Animate window again (select *Animate Tool* from the *Edit* menu) and step thru time to see the magnetic field-line reversal region move up and down in our GSM view frame as the dipole field (aligned with the blue axis) changes its orientation relative to the solar vector. Set the time slider to 15:00 06/09/1989 using the slider arrows. The graphic should resemble the following figure.

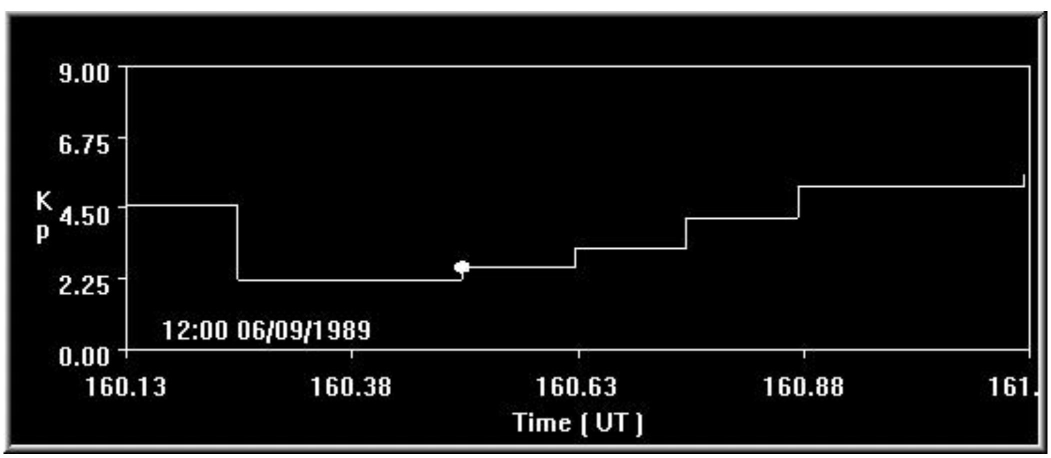


Display Dynamic Sequence of Magnetic Field Coordinate Slices in 3-D,

- To display the magnetic field magnitude values stored on our SM grid, select *Coord Slice* from the *Available Modules* list. A *Coord Slice* object appears in the *Active Modules* list and a set of Coordslice Options appear in the Environment Window.

- Click on the *Data* button and choose */B/* under the *AppBfield* option and click *Display*. Display the color bar by activating the *Show Color Bar* option in the *Viewport* menu. If the coordinate slice does not appear on the nightside of the Earth, use the *Animate Tool* (in *Edit* menu) to get all graphics display for the same time. To get a contour of magnetic field strength in the Y-GSM plane select Cut Plane *C1*, move the *Position Value* slider to 0.500.





- View the sequence using the *Animate* switch in the *Animate* Window. Notice that the minimum field strength region (dark blue) corresponds to the magnetic field reversal region. This minimum field strength region is also the location of the cross-tail current system that

contributes to the sharp field reversal. In this situation, as the North magnetic pole tilts toward the Sun the field reversal region and current sheet move above the GSM z= 0 plane. Set the animate slider to 12:00 06/09/1989 so that the graphic resembles the upper figure above.

Display and Track Geomagnetic Index Kp in 1-D,

- Select *Create 1D Viewport* from the *Window* menu and a 1-D graphic window will appear distinguished by white line border. Select the *Tile* option from the *Window* menu to view both existing graphic windows together. Place the mouse cursor in the 1-D window and click to activate that window. Place the time/date label in the 1-D window by highlighting the *Annotation* entry in the *Active Modules* list (on the right) and selecting *Display*. The label will appear in the lower left corner of the 1-D window.

- Scroll down the *Available Modules* list and select *Global Inputs*. A *Global Inputs* object will be added to the *Active Modules* list and a set of Global Input Options will appear in the Environment Window. From the *Value* input section, select the *Kp* option and click *Display* to produce a plot of Kp versus time. To clean up this 1-D plot, reset the Y Axis text fields *Min* = 0.0 and *Max* = 9.0. Click the mouse in any other text field to update the plot. The 1-D plot should resemble the lower figure above. This profile of the geomagnetic index Kp was used to drive the Tsyganenko '89 magnetic field model.

- Use the *Animate* window to view the magnetic field changes as the magnetic activity index Kp changes. Typically, the geomagnetic field becomes more stretched on the nightside as the Kp index increases, i.e., the magnetic field lines become gradually more stretched after 09:00 06/09/1989. Again, the field reversal region rises above the GSM z = 0 plane as the dipole tilt angle becomes more positive (blue axis points more sunward).

This completes the Example of The Earth's Magnetic Field: Placement of the Current Sheet

4) UHF/L-Band Scintillation on a Geostationary Downlink (V2.5.1 Only)

The following example demonstrates the use of the WBMOD (WideBand Model) Science Module and a variety of other visualization tools.

Goal: The WideBand Model (WBMOD) specifies scintillation parameters between locations on the globe and a satellite above 100 km altitude as a function of signal frequency and geomagnetic activity. Scintillation is the rapid amplitude and phase fluctuations of signals passing through ionospheric irregularities. The goal of this example is to determine where the disturbance level of scintillation (S4) of UHF (250 MHz) and L-Band (1500 MHz) signals will be severe at least 10% of the time for ground-based receivers within the footprint of a geostationary satellite under moderately active solar/magnetic conditions.

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this static run, set the Global Parameters as follows: *Start:Year*=1990, *Day*=260, *UT*=21:00. The *Kp* and *SSN* (sunspot number) corresponding to the specified date and time may now be obtained by clicking on the *Globals*: *Archive* option to the right of the time input fields. The NGDC archived values of these parameters are then automatically loaded (*Kp*=3, *SSN*=137, *F10.7* =210.7, and *Ap*=15). Note that *Year*, *F10.7* and *Ap* are not used by WBMOD. These parameters describe conditions following passage of the solar terminator in the Euro-African longitude sector during moderate magnetic and solar activity conducive to the development of scintillation near the magnetic equator on September 17, 1990.

- Choose *Modules* from the Environment Window Menu Bar and select *Science* from the options. *Available Modules* and *Active Modules* lists will appear.

- Scroll to the bottom of the *Available Modules* list and click on *WBMOD*. A SciWbmod object will be added to the *Active Modules* list and a WBMOD Options panel will appear in the Environment Window. To model the upper 10% (90th percentile) of 250 MHz scintillation observed on the ground from a geostationary satellite located over the Atlantic Ocean set the WBMOD options: Propagation=*1-Way*, In-situ Vd=*Model*, Step=*Rcvr*, EP Boundary=*Use Kp*, Output=*Percentile*, *Trans. Freq (MHz)*=250, *Trans. Alt. (km)*=36000, *Fixed End Lat*=0, *Fixed End Lon*= -15, *Phase Stability(s)*=10, *Percentile*=0.9, and *Kp@LocalSunset*= -1. All other input parameters remain inactive.

- Select the *Run/Update* option in the *Edit* menu. The *Model Status* box will. When the run is complete the Process View Window will disappear and the *Model Status* box will be updated with the text “MODEL IS READY AND UP TO DATE” and the Global Parameters used to construct the model run.

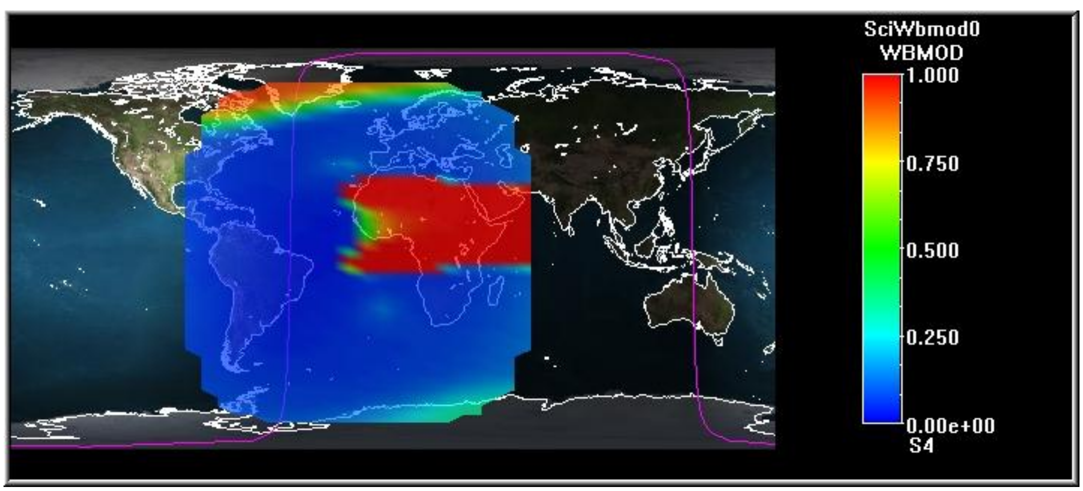
Plot UHF WBMOD Results in 2D,

- Return to the Menu Bar at the top of the Environment Window, click on *Modules* and select *Graphics*. *Available Modules* and *Active Modules* lists will appear. Scroll down and select *Earth* from the *Available Modules* list. An *Earth* object will be added to the *Active Modules* list and an Earth Options panel will appear in the bottom of the Environment Window. Select *Textured* and *Geographic Bndys* under Outline Detail. Select *Terminator* under Grid Options. Click in the *Display* box in the Environment Window and the Earth will be displayed in the 3D Window; a purple line shows the location of the solar terminator at the surface.

- Change the 3D projection of Earth to a 2D projection by using the *Viewport* menu to select *Projection* and then *Two D*. The default 3D window should now have been converted to a 2D window with an Earth map.

- Select *Coord Slice* from the *Available Modules* list. A *Coord Slice* object will be added to the *Active Modules* list and a corresponding options panel will appear in the bottom of the Environment Window. Under Coord Slice Options click on the *Data* button, slide down the popup menu to the *SciWbmod* option, and select *S4*. Click in the *Display* box to display the scintillation results on the 2-D map.

- Select the *Transparency* button in the Coord Slice Options panel. Increase the transparency of the S4 plot by moving the *Transparency* slider to a value of 0.7 and uncheck the *Lighting* option. Select the *Data Map* option and set *Data Min* = 0.0. The plot should resemble the following figure.



Create WBMOD Model Output for L-band (1.5 GHz),

- Click on *Module* menu and select *Science* and *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list on the left and select *WBMOD* again and a second *SciWbmod* entry appears in the *Active Modules* list on the right. The WBMOD Options panel will appear in the bottom of the Environment Window.

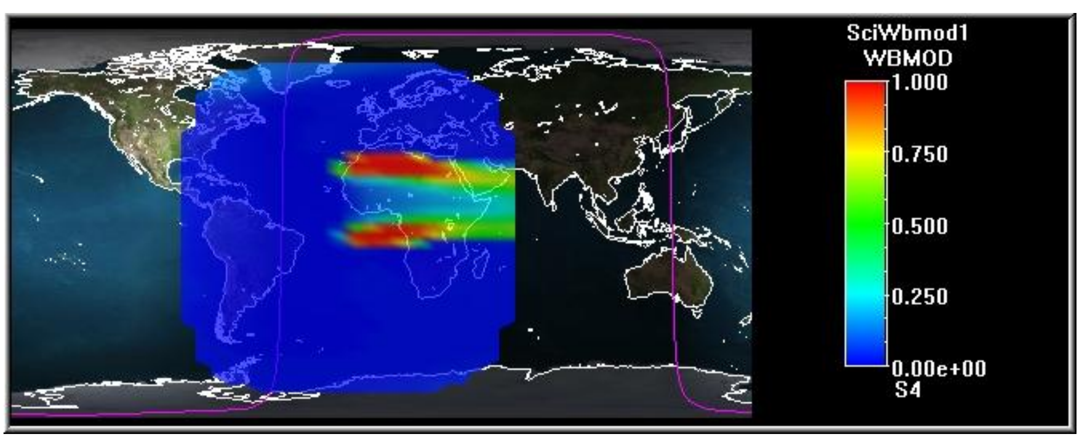
- To model the upper 10% (90th percentile) of 1500 MHz scintillation observed on the ground from a geostationary satellite located at the equator over the Atlantic Ocean set the following WBMOD options: Propagation=*1-Way*, Step=*Rcvr*, Output=*Percentile*, *Trans. Freq (MHz)*=1500, *Trans. Alt. (Km)*=36000, *Fixed End Lon*= -15, *Percentile*=0.9, and *Kp@LocalSunset*= -1. All other WBMOD parameters may be left at the default values. These inputs are the same as those entered to get the existing 2D plot except for the increase in *Trans. Freq (MHz)*. Note that the Global Parameters at the top of the Environment Window set earlier do not change.

- Select the *Run/Update* option in the *Edit* menu and after the View Process Window has disappeared and the *Model Status* box has been updated, there is a second WBMOD data set available for display.

- Return to the Menu Bar at the top of the Environment Window, click on *Window* and select *Create 2D Viewport*. A second 2D Window will appear. Click on the *Window* menu again and select *Tile*. The graphic area should now be shared by the 2D windows.

- Return to the Menu Bar at the top of the Environment Window, click on *Module* and select *Graphics*. *Available Modules* and *Active Modules* lists will appear. The *Active Modules* list will already contain *Earth* and *Coord Slice* objects from the UHF results plot. Select *Earth* from the *Active Modules* list on the right, click in the empty graphics window to activate it, and check the *Display* box. This procedure simply places a copy of the Earth with terminator in the new window.

- Select *Coord Slice* from the *Available Modules* list on the left. A second *Coord Slice* object will be added to the *Active Modules* list and a set of Coord Slice Options will appear in the bottom of the Environment Window. Under Coord Slice Options click on the *Data* button, slide down the popup menu to the second *SciWbmod* option, and select *S4*. Click in the *Display* box to display the scintillation results on the new two-dimensional map. To reproduce the final figure, click on the *Transparency* button and set the slider value to 0.7 and then uncheck the *Lighting* option.



Interpretation of Results: The results indicate that the 90th percentile of S4 index at 250 MHz within 20 degrees of the magnetic equator over most of Africa at 21:00 UT will be unity, i.e., severely scintillated at least 10% of the time (i.e., 1 out of 10 days) for the geophysical conditions specified (see first plot made). Recall, for the step-receiver mode, the data will be plotted at the receiver location, not at the ionospheric location where scintillation occurred. Similarly, in the step-transmitter mode, data is for scintillation on the ray-path from the satellite to the receiver and plotted at the sub-satellite point. This display location would not be the ionospheric location where the scintillation occurred. As expected, the level of scintillation experienced by L-band (1.5 GHz) signals is substantially lower over most of the affected region (see second plot). The 95th percentile fade (dB) can be displayed by returning to the Coord Slice Options panel (select *Graphics* under the *Module* menu, click on the second *Coord Slice* in the *Active Modules* list) and selecting *95%tile FADE* from the second of the WBMOD *Data* options. Both UHF and L-band results may be obtained in this manner by selecting the *Coord Slice* entry that corresponds to each frequency. Do not confuse this percentile with the climatological percentile input to run WBMOD. For example, we selected a 90th percentile climatology for this example. This display represents the 5th most severe fade on the 10th most disturbed day. Recall, that scintillation is the rapid fluctuation of the signal's amplitude and phase. Therefore, if any of the fades are below the receiver's fade-margin even for small amounts of time, this may be enough to cause communication problems, especially if the message is encrypted.

This completes the Example of UHF/L-Band Scintillation on a Geostationary Downlink.

5) HF Ray-Tracing in the Ionosphere

The following example demonstrates the use of the Parameterized Ionospheric Model (PIM) Science Module, the 2-D ray-tracing Application Module, and a variety of visualization tools.

Goal: Electron density variations in the ionosphere determine how radio communications signals propagate. Signals tend to bounce off regions where the local critical plasma frequency is greater than the signal frequency (high electron density correlates with high critical plasma frequency). Therefore, an HF signal transmitted from a ground station with just the right frequency can experience multiple "hops" and be received at several geographic locations along its ray path. The goal of this example is to generate ionospheric data sets, including 3D electron density profiles and a 2D map of critical frequencies in the F2 layer (called foF2), and examine how HF rays propagating from ground-based transmitters follow frequency dependent paths, i.e., travel different distances before returning to the Earth's surface.

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this static run, set the Global Parameters as follows: *Start:Year*=1991, *Day*=187, *UT*=00:00. Click on the *Archive* option of the *Globals* button and the Kp, SSN (sunspot number), F10.7 radio flux, and Ap index corresponding to the specified date and time will be loaded automatically from archived NGDC values (*Kp*=1.3, *SSN*=204, *F10.7*=240.8, and *Ap*=5).

Create a PIM Model data set,

- Choose *Modules* from the Menu Bar and select *Science* from the options. *Available Modules* and *Active Modules* lists will appear. Scroll down in the *Available Modules* list and click on *PIM*. A PIM object will be added to the *Active Modules* list on the right and a set of PIM Options will appear in the Environment Window.

- Click on the *IMF By* menu button and select *Positive*. Leave the other options at their default values. These settings will run PIM with no normalization under conditions with a positive Interplanetary Magnetic Field (IMF) B_y component and negative B_z component. The default grid is set to 2° latitude x 5° longitude, the resolution most compatible with the ray-tracing program. The PIM model results are written to the default output file named "pim_pud.out".

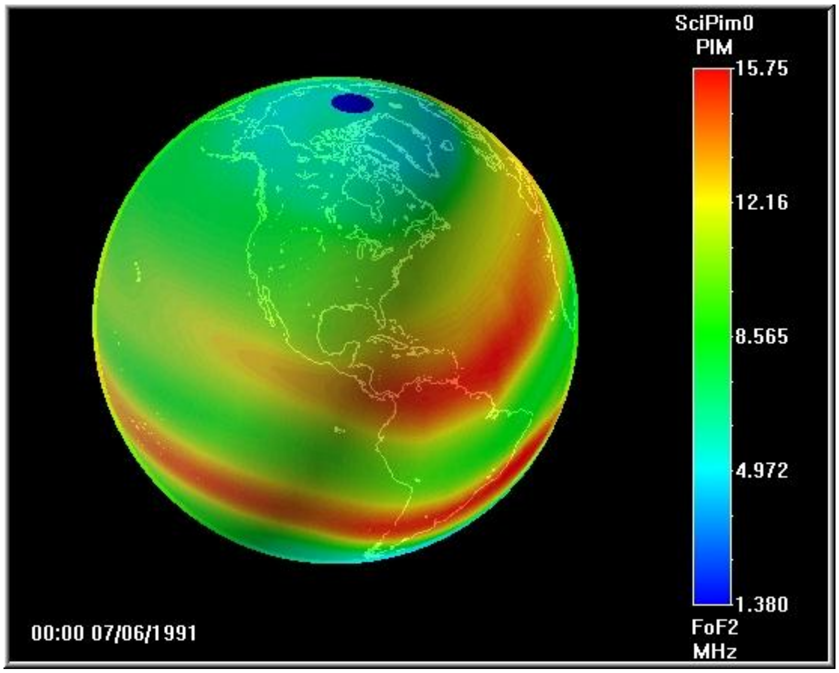
- Select the *Run/Update* option in the *Edit* menu. When the *Process View* Window disappears the *Model Status* box will indicates the Global Parameters used.

Plot the PIM critical frequency profile in the F2 layer (called foF2),

- At the top of the Environment Window, click on *Module* and select *Graphics*. *Available Modules* and *Active Modules* lists will appear. Select *Earth* from the *Available Modules* list.

An *Earth* object will be added to the *Active Modules* list and an Earth Options panel will appear in the bottom of the Environment Window. Click in the *Display* box in the Environment Window and the Earth will be displayed in the 3D Window.

- Select *Coord Slice* from the *Available Modules* list. A *Coord Slice* object will be added to the *Active Modules* list and a corresponding options panel will appear in the bottom of the Environment Window. Use the *Data* button to select the *FoF2* option under *SciPim*, click the *Display* box to place the FoF2 coordinate slice in the 3D window. Next select *Transparency* and adjust the slider that appears at the bottom of the window to a value of 0.75.



- Select *Annotation* from the *Available Modules* list and an *Annotation* object will be added to the *Active Modules* list and Annotation Options will appear. Place a check mark in the *Show Date* box and click *Display*. A time/date label appears in the lower left corner of the graphic window. Reset the *X Position* and *Y Position* sliders to 0.04 to make the label easier to read.

- Highlight the *Coord Slice* entry in the *Active Modules* list on the right and the FoF2 color bar will reappear in the graphic window. Use the left and right mouse buttons to rotate and rescale, respectively, the view until it resembles the figure above.

Plot HF Ray-Traces,

- At the top of the Environment Window, click on *Module* and select *Applications*. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select RAYTRACE-APP. An *AppRayTrace* entry will appear in the *Active Modules* list and a selection of Ray Tracing Application options will appear.

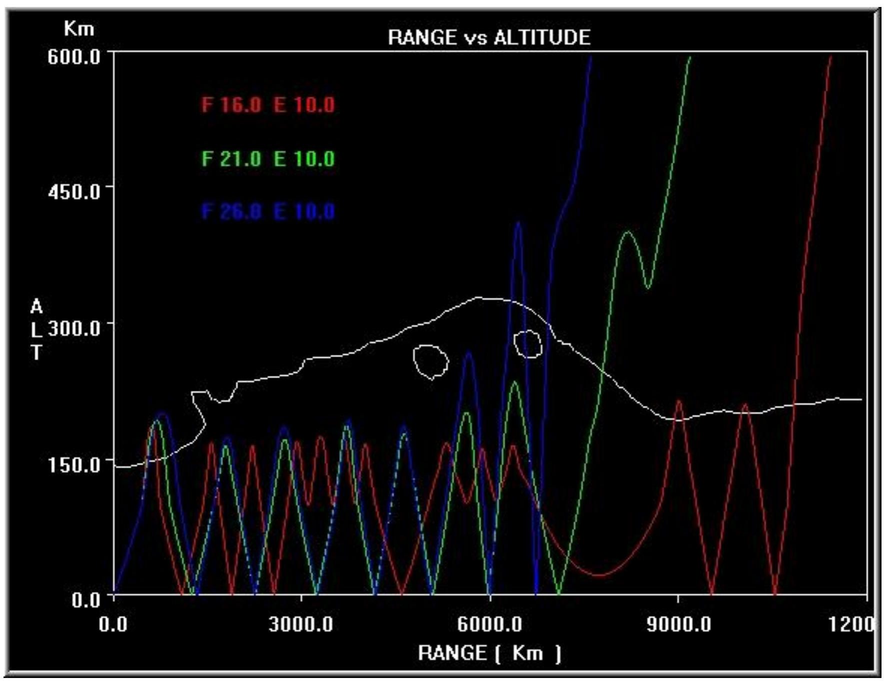
- Leave the Model: *Australian 2D* selection. In the Freq (MHz) input section pick *Multi* and set the *Freq(MHZ)* parameters to go *From* 16 *To* 26 with a *Step* of 5.0. In the Elev (deg) section select *Single* and set the *Single* value to 10 degrees. Leave the *Azimuth, Range(1000 km)*, and *Max Hops* settings at their default values. Adjust the Transmitter Location settings to reflect Bangor Maine as the location, i.e., set *Lat* = 44.8 degrees and *Lon* = -68.8 degrees.

- To perform the ray traces through the PIM ionosphere just calculated, click on the *Open Pim File* button and open the file "pim_pud.out" found in the SciPim folder newly created in the Scratch Directory.

- To trace the selected rays, select the *Run/Update* option in the *Edit* menu. The *View Process* Window will vanish when the ray tracing is complete.

- Click on the *Display Plot* button and a 2D plot will fill the graphics display window. Now click on the *Plot Options* button to adjust this ray trace plot. In the *Ray Plot Options* window, click on the *Captions* button and the *Plasma Frequency* button. Move the *Plasma Frequency* slider to 0.90 MHz and click OK. The plot should now look like the following figure.

- The same set of ray trace can be viewed in a 3D window by using the *RayTrace* graphic and choosing the only *Data* button option available.



This completes the Example of HF Ray-Tracing in the Ionosphere.

6) The Energetic Solar Event of 20 February 1994 (V2.5.1 Only)

The following example demonstrates the use of the Interplanetary Shock Propagation Model (ISPM), Shock Time of Arrival (STOA), and Proton Prediction System (PPS) Science Modules.

Goal: High-speed interplanetary shocks originate near the Sun's surface and propagate out into the solar system to disrupt the character of the nominally steady solar wind. Large shocks that hit the Earth's magnetosphere can drastically change the near-earth particle and electric and magnetic field environment and affect the operation of man-made systems. Energetic protons, also originating with solar disturbances, arrive on much shorter time scales and can penetrate deep into the near-earth environment and adversely affect both instruments and biological systems. The goal of this example is to investigate the forecasting capabilities of ISPM, STOA, and PPS using observations of the energetic solar event of 20 Feb 94 and subsequent terrestrial effects. The energetic solar event involved a disappearing filament and an M4/3B flare at 0104UT on 20 Feb 94. This event was responsible for enhanced levels of energetic protons observed by the GOES satellite at geosynchronous orbit and is believed to have caused a CME/shock that arrived at the Earth the next day. All input data were taken from the NOAA Solar-Geophysical Data Preliminary, Prompt, and Comprehensive Reports.

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this static run, set the global time parameters to match the observed solar flare time, i.e., set *Start:Year*=1994, *Day*=51, and *UT*=01:04. Click on the *Globals: Archive* selection to the right of the time inputs to automatically load the appropriate parameters from the NGDC archive (*Kp*=4.7, *SSN*=16, *F10.7*=105.2, and *Ap*=39). None of these global parameters are used as inputs for this example.

Run the ISPM and display text results,

- From the *Modules* menu at the top of the Environment Window, select the *Science* option. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and click on *ISPM*. A *SciIspm* object will be added to the *Active Modules* list and a set of ISPM Options will appear in the Environment Window.

- Under Specify Event Duration, select the *X-ray Levels* option. We will use the GOES 7 1-8 Angstrom X-ray data to determine the duration of the event. Leave the *Event in the previous 24 hours?* box empty as there were none.

- Both Palehua and Learmonth RSTN sites observed Type II radio bursts for this event with estimated shock speeds of 1000 km/s and 1400 km/s, respectively, starting at 0108UT. An H-alpha flare of magnitude 3B was observed on the solar surface at N09 and W02 by Learmonth at 0138UT and lasted for 90 minutes. Given this, edit the *Event onset time* text

box to read “02/20/94 01:08”, set *Flare lat (deg N)* =9, and *Flare lon (deg W)* =2. Assume the shock velocity to be the average of the two observations and set *Type II speed (km/s)* =1200.

- Examining the GOES 7 X-ray data in the 1-8 Angstrom band, the background classification before the event was approximately B2.0 and the classification of the peak of the event was M4.0. Enter *Backg. Class* =B2.0 and *Peak Class.* =M4.0. Further examination of the GOES data indicates that after the peak of the X-ray event, the level decayed to class C2.8 at about 0320UT on 2/20/94. Edit the *Event end time* text box to read “02/20/94 03:20”.

- Select the *Run/Update* option in the *Edit* menu to execute ISPM and a text box will appear containing the following results. The *Display Text* button redisplays the text result.

```
---- ISPM - Interplanetary Shock Propagation Model  - Version 1.0 ---------

Shock will reach Earth                      1994 02 21   1109Z
Total propagation time                      34h 01m
Shock strength (jump in dynamic pressure),  6.8  dynes/cm2  x 10-8

Shock Strength Index, SSI                   1.1
if > 0  expect shock to be sufficiently strong
magnitude of SSI reflects strength of shock,
if = 0, then shock strength borderline
if <-1, then expect no effects

Input Parameters:

Type II onset time          1994 02 20   0108Z
X-ray event end time        1994 02 20   0320Z
Driver duration              2h 12m,  reset to 2.0h

Energy input by flare        7.4   x10+30 erg

Type II speed                1200.0  km/s
Solar flare at              N09 W02  deg

--------------------------------------------------------------------------
```

The ISPM results above show that a shock will reach Earth at 11:09 UT on 02/21/94 with a dynamic pressure jump of 6.8e-8 dynes/cm^2 after traveling for a period of 34 Hours and 01 minute. Ground magnetometer data show that a Sudden Impulse occurred at 09:01UT 02/21/94 indicative of the passage of a solar wind shock by the Earth. This is confirmed by solar wind data from the IMP8 spacecraft showing a shock passage with a dynamic pressure jump of about 1.6e-7 dynes/cm^2. In this case ISPM predicted the shock arrival two hours late (a 6% error in overall propagation time) and a dynamic pressure jump smaller than observed by a factor of 2.4.

Run the STOA model and display text results,

- Scroll down the *Available Modules* list and click on *STOA*. A *SciStoa* object will be added to the *Active Modules* list, and a set of STOA Options will appear in the Environment Window.

- Under “Specify Event Duration” select the *X-ray Levels* option. We will use the same GOES 7 1-8 Angstrom X-ray data we used for the ISPM module. As in the ISPM case, enter the following data in the appropriate boxes so that the STOA program can compute event duration: *Event onset time* = “02/20/94 01:08”, *Flare lat (deg N)* =9, *Flare lon (deg W)* =2, *Type II speed (km/s)* = 1200, *Back. Class.* =B2.0 and *Peak Class.* =M4.0. Click in the *Decay time* text box (and label will change) and edit the *Decay time, level=C2.8* text box to read “02/20/94 03:20”.

- In the STOA model we have the option of entering a solar wind speed. Enter *Solar wind speed (km/s)* =400 to match the value used by default in the ISPM case. It should be noted that the real solar wind speed can be quite variable. On 02/20/94 the IMP-8 satellite recorded a solar wind speed that varied from about 580 km/s at 08:00 to about 500 km/s near the end of the day. Prior to 08:00 there was a data gap on that day. The next morning the solar wind speed had decreased to about 400 km/s by 01:00. Another data gap ensued and then the solar wind speed was 400 km/s from about 07:20 until the time of the observed shock at 09:00.

- Select the Earth option under Observer Location.

- Select the *Run/Update* option in the *Edit* menu to execute STOA and a text box will appear containing the following results. The *Display Text* button redisplays the text result.

```
--------- STOA - Shock Time of Arrival - Version 1.0 ---------

         Mach   5.4 shock will reach Earth     1994 02 21   2309Z
         Total propagation time                  46h 01m

         Type II onset time          1994 02 20   0108Z
         X-ray event end time        1994 02 20   0320Z
         Driver duration              2h 12m

         Type II speed                1200.0  km/s
         Solar flare at              N09 W02  deg
         Solar wind speed              400.0  km/s

         Sun-Earth distance           0.9889  AU

---------------------------------------------------------------
```

The above STOA results show that a Mach 5.4 shock will reach Earth at 23:09 UT on 02/21/94, after traveling for a period of 46 hours and 01 minute. This is 14 hours and 08 minutes later than the observed shock described earlier, and exactly 12:00 hours later than the ISPM predicted time.

Run PPS and display text results,

- Click on *PPS* in the *Available Modules* list. A *SciPPS* object will be added to the *Active Modules* list and a set of Proton Prediction system (PPS) Options will appear in the Environment Window.

- Under Specify Data, select the *Radio* option and under Specify Flux Type, leave *Peak Flux* as the default flux type. Also leave the *Radio Frequency* button set at the default value of *2695* MHz. Since we are considering the same event as discussed above enter *Flare lat (deg N)* =9 and *Flare lon (deg W)* =2.

- The Palehula RISTN site observed a 2695 MHz fixed frequency radio emission event beginning at 0105UT on 2/20/94 and reaching a maximum at 0114UT with a duration of 85 minutes and a peak flux of 190 SFU. Edit the *Event Onset Time* text box to read “02/20/94 01:05”, set *Time of Maximum* = “02/20/94 01:14”, and set *Peak Radio: RAD26P(SFU)* =190.

- Select the *Run/Update* option in the *Edit* menu to execute PPS and a text box will appear containing the following results. The *Display Text* button redisplays the text result.

```
---- PPS - Proton PredictionSystem-Version '95 ----


 Maximum  day  polar riometer absorption   will be     1.64 db  at 10:51 Feb 20
 Maximum night polar riometer absorption   will be     0.63 db  at 12:22 Feb 20

 70000 ft high flyer polar max dosage  will be       0.0 mR/hr  at 08:10 Feb 20
 50000 ft high flyer polar max dosage  will be       0.0 mR/hr  at 08:07 Feb 20

 E V A          max. astronaut dosage  will be      0.005 R/hr  at 10:10 Feb 20
 Inside  [ 2 gm/(sqcm) ]   max dosage  will be      0.001 R/hr  at 08:55 Feb 20

 Protons: >10 MeV gt 10  Feb 20 10:00 to Feb 20 21:00; max flux of  1.83E+01  at 10:01 Feb 20
                                                       fluence  of  1.11E+06
 Protons: > 5 MeV gt 10  Feb 20 11:00 to Feb 21 07:00; max flux of  2.99E+01  at 11:12 Feb 20
                                                       fluence  of  1.90E+06
 Protons: >50 MeV gt 10      00 00:00 to     00 00:00; max flux of  7.44E-01  at 08:48 Feb 20
                                                       fluence  of  4.65E+04

 Input Parameters:

 Input Type:           RAD26PP

 Date of onset:        02/20/94
 Time of onset:        01:05
 Time of maximum:      01:14

 Event lat (deg N):         9.00
 Event lon (deg W):         2.00
 Event amplitude:      1.90E+002

 Expert mode parameters:

 Normalization energy channel: 0
 Flux normalization value: 0
 Time of flux maximum:00/00 00:00

 Slope of integral spectrum: 0.0
 Slope of differential spectrum: 0.0
```

In the above results, PPS predicts that the > 10 MeV proton flux at the Earth, as measured by the GOES satellite, will exceed a threshold of 10 protons/(cm^2 s sr) for a period beginning at 10:00UT 02/20 and ending at 21:00UT 02/20/94 with a maximum flux of 18.3 ptns/(cm^2 s sr) at 10:01 02/20/94. The same flux threshold will be exceeded by the > 5 MeV flux beginning at 11:00UT 02/20/94 and ending at 07:00UT 02/21/94 with a maximum flux of 29.9 ptns/(cm^2 s sr) at 11:12 02/20/94. For the > 50 MeV protons the threshold is never reached and the maximum flux is 0.744 ptns/(cm^2 s sr) at 8:48 on 02/20/94. In this example we will not consider the user-specified quantities that are also displayed in the PPS output window. These include polar riometer absorption forecasts and maximum radiation dosages at specific altitudes, and are described in the manual pages for the PPS Science Module.

Examining the GOES-7 proton data for this interval it can be seen that the > 5 and > 10 MeV fluxes both exceed the threshold value at about 03:00UT 02/20/94. The first maximum of the > 5 MeV flux is reached at about 09:45UT 02/20/94 and has a value of about 220 protons/(cm2 s sr). Likewise, the first maximum of the > 10 MeV flux is reached at about 06:00UT 02/20/94 and has a value of about 80 ptns/(cm^2 s sr). The maximum value of the > 50 MeV channel is reached at roughly 03:00UT and has a value of about 1.5 ptns/(cm^2 s sr). For this event, PPS does a reasonable job for the > 50 MeV fluxes and gets progressively worse for the lower energy channels, overestimating transit times and underestimating intensities. This event, however, turns out to be a fairly rare example of a "hybrid" solar proton event. Besides the initial population of energetic protons generated by the energy release near the Sun (the population that PPS is built to model), there is another population of energetic protons reaching the Earth that is generated by the energetic interplanetary shock traveling towards the Earth (i.e., the shock that ISPM and STOA are modeling). Indeed, after the initial rise and a very small decay, the >5 and >10 MeV fluxes rise again to reach a maximum of 4.e+4 and 8.e+3 ptns/(cm^2 s sr), respectively, at 09:00UT on 2/21/94. This is exactly when the interplanetary shock arrived at Earth. A combination of an unexpectedly strong shock with the correct propagation path towards Earth made this event one of the strongest solar proton events of solar cycle 22.
This completes the Example of The Energetic Solar Event of 20 February 1994.

7) The Magnetic Storm of 13 March 1989 (Dynamic)

The following example demonstrates a dynamic application of the aurora science module (AURORA) and a variety of visualization tools including the creation of a station, animation of 2-D and 3-D coordinate slices, and tracking of global input parameters.

Goal: On March 13th 1989, the second largest geomagnetic storm in the past 50 years hit the Earth's magnetosphere causing havoc with the power grid serving Canada's Quebec province. At 2:45 AM EST (Day 72, UT 0745) widespread geomagnetically induced currents (GIC) caused transformer saturation at the Hydro-Quebec power system on James Bay resulting in electric service outages for the following nine hours in the Quebec province. Voltage fluctuations were first noticed on March 12. The goal of this example is to view the dynamic sequence of auroral precipitation (statistical distribution) as it sweeps over James Bay and the Quebec province area in the North American sector in response to changes in the observed geomagnetic index Kp.

Start a dynamic AF-GEOSpace session and set global input parameters,

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- Establish a dynamic session by placing a check mark in the small box to the right of the *Start: UT* text field to activate the *End: Year, Day, UT* text fields. Edit the *Start* text fields so that *Year* = 1989, *Day* = 71, and *UT* = 12:00. Edit the *End* text fields so that *Year* = 1989, *Day* = 72, and *UT* = 21:00. From the *Globals:* selector options (on the same bar as the time inputs) pick *Archive* to automatically load parameters from the NGDC archive.

- View the global parameters for the interval selected using the *Globals* menu (between the *Viewport* and *Help* menus at the very top of the environment window) and selecting the *Show* option. Scroll down the *Globals* text window that appears and notice that the Kp geomagnetic activity index reaches its maximum level of 9 near the end of the interval selected. Dismiss the *Globals* text window using the *Save* or *Cancel* buttons at the bottom.

Display plot of Geomagnetic Index Kp in 1-D,

- Convert the default 3-D graphics window to a 1-D window by using the *Viewport* menu, selecting *Projection* and then the *One D* option. (1-D windows are identifiable by the white line framing the graphic window border). Note that a 1-D window can be converted back to a 3-D window at any time by repeating this step and selecting the *Three D* option instead. Also, converting a window between 1-D and 2-D or 3-D (or vis-a-versa) results in the loss of the graphic in the window but not the graphics object in the Graphics *Active Modules* list.

- Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Global Inputs*. A *Global*

Inputs object will be added to the *Active Modules* list and a set of Global Input Options will appear in the Environment Window.

- From the *Value* input section, select the *Kp* option and click *Display* to produce a plot of Kp versus time. To clean up this 1-D plot, reset the Y Axis text fields *Min* = 0.0 and *Max* = 9.0. Click the mouse in any other text field to update the plot. This profile of the geomagnetic index Kp will be used below to drive a sequence of auroral precipitation patterns to emulate the March 1989 event. We will retain this plot for later viewing.

Display Earth with Quebec and James Bay locations,

- Select the *Create 3D Viewport* option from the *Window* menu and a new 3-D window will fill the graphics area to cover the 1-D Kp vs. time plot just created. Note that there are several options are handling windows listed in the lower part of the *Window* menu, e.g., the two existing windows can be arrange using the *Cascade* or *Tile* options. A list of numbered window references appear at the bottom of the Window menu and more are added to the list as new windows are created, i.e., currently the entries *1:1* and *2:2* can be used to bring the 1-D and 3-D windows to the foreground. Check that the 3-D window is currently being viewed (the *2:2* option of the *Window* menu)

- Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Select *Earth* from the *Available Modules* list. An *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear in the Environment Window.

- Under Outline Detail, select *Textured* and *Geographic Bndys*. Under Grid Options select *Lat/Lon Grid*, and then select *Display* and the Earth globe will appear in the 3-D window.

- To create and display a station marker representing the location of Quebec Canada, scroll down the *Available Modules* list and select *Station* and a *Station* object will be added to the *Active Modules* list. If Quebec does not appear on the Stations list, then a new station entry can be added by editing the four text boxes appropriately, i.e., set *Lat* = 46.80, *Lon* = -71.25, *Alt(Re)* = 1.0, and *Label* = "Quebec" and click the *Add* button. A highlighted *Quebec* entry will appear in the *Stations* list. Click *Display* and a Quebec marker will appear. Use the *Pop Label* feature to make the station always visible. Note: Stations can be removed from the list by highlighting the entry in the *Stations* list and clicking on the *Delete* button. All changes to the *Stations* list will be saved for future sessions.

- Create and display a station marker representing the location of James Bay Canada by repeating the last step with the Station inputs set as *Lat* = 52.0, *Lon* = -80.0, *Alt(Re)* = 1.0, and *Label* = "James Bay". This will result in a second *Station* entry in the *Active Modules* list. With no data plotted, use the *Viewport* menu to turn off *Show Color Bar*.

- The Earth's size can be scaled in the 3D Window using the right mouse button. With the cursor in the 3D Window, depress the right button and draw the mouse toward yourself. Rotate the Earth so that the Quebec and James Bay location markers are visible using the left mouse button.

Generate a Dynamic Auroral Sequence,

- Select the *Science* option in the *Module* menu and *Available Modules* and *Active Modules* lists will appear. Click on *AURORA* in the *Available Modules* list and a *SciAurora* object will be added to the *Active Modules* list. A set of AURORA Options will appear in the Environment Window.

- Select the *Gridded Data* option in the Generate input section. Leave the Internal B-Field and External B-Field selections set at their default values.

- Select the *Dynamic Tool* option in the *Edit* menu and a *Dynamic Tool* option window will appear. Place a check mark in top two rows of Variables noted at the top. Edit the *Time Step (sec)* text field to read 10800 seconds and click the *Update List* button. These settings indicate which available AURORA science model output variables will be calculated during the Start/End period at intervals of 3 hours (10800 sec). Click the *Done* button to register your selections and dismiss the *Dynamic Tool* window.

- Select the *Run/Update* option in the *Edit* menu and a *Process View* Window will appear. As the model is completed for each time step, the *Model Status* box is updated to indicate the model run time and the Global Parameters *Day*, *Time*, and *Kp* used. When the complete set of model runs is complete the *Process View* Window disappears.

Display the Dynamic Sequence of Auroral Electron Precipitation Patterns in 2-D and 3-D,

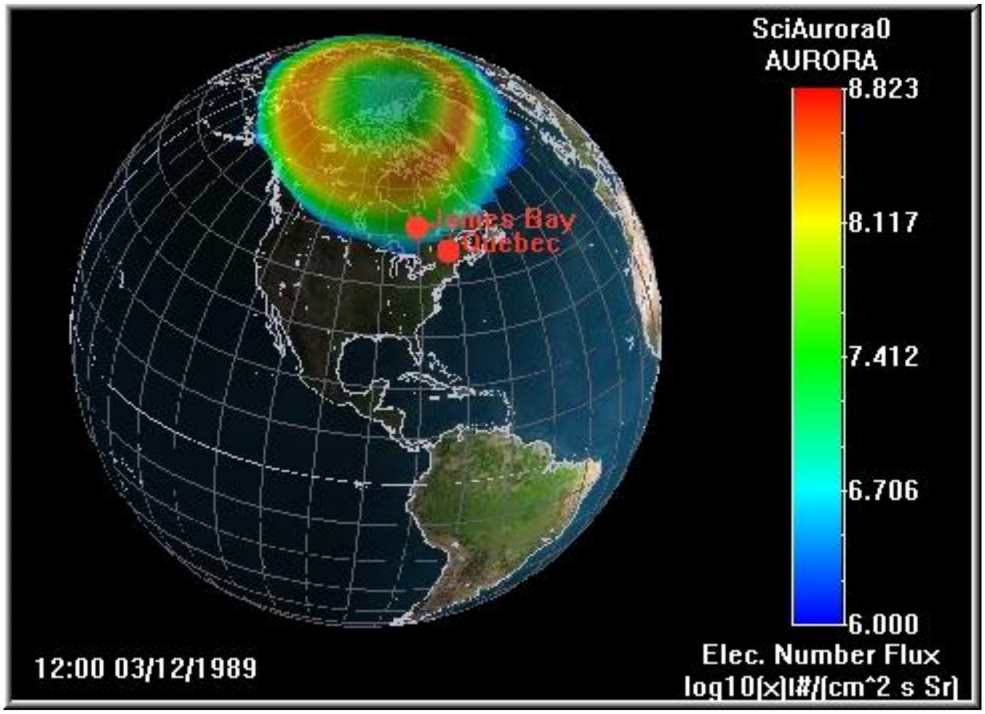
- Select the *Graphics* option in *Module* menu and *Available Modules* and *Active Modules* lists will appear. Select *Coord Slice* and a *Coord Slice* object will be added to the *Active Modules* list. A set of Coord Slice Options will appear in the Environment Window. Use the default setting under Cut Plane option *C0* to slice the data at a constant radius. Note that the default grid for AURORA consists only of two constant radius caps at the Earth's poles.

- Click the *Data* button, go to the *SciAurora* option, and select *Elec. Number Flux*. Click in the *Display* box and auroral electron data will appear in the 3D Window. From the *Viewport* menu, use the *Show Color Bar* option to show the color bar with units now representing auroral electron number flux. The displayed data type can be changed to view Ion or conductivity variables by resetting the *Data* button in the Coord Slice Options window (highlight the *Coord Slice* entry of the graphics *Active Module* window to view these options).

- To make the auroral display more transparent, click the *Transparency* button in the Environment Window and move the slider to a value of 0.70. Rotate the Earth and notice that the auroral electron number flux is displayed at both poles.

- To display a time label in the graphics window, select *Annotation* from the *Available Modules* list and an Annotation object will be added to the *Active Modules* list. A set of Annotation Options will appear in the Environment Window. Place a check mark in the *Show Date* box and click *Display* and a time/date label will appear in the far lower left corner of

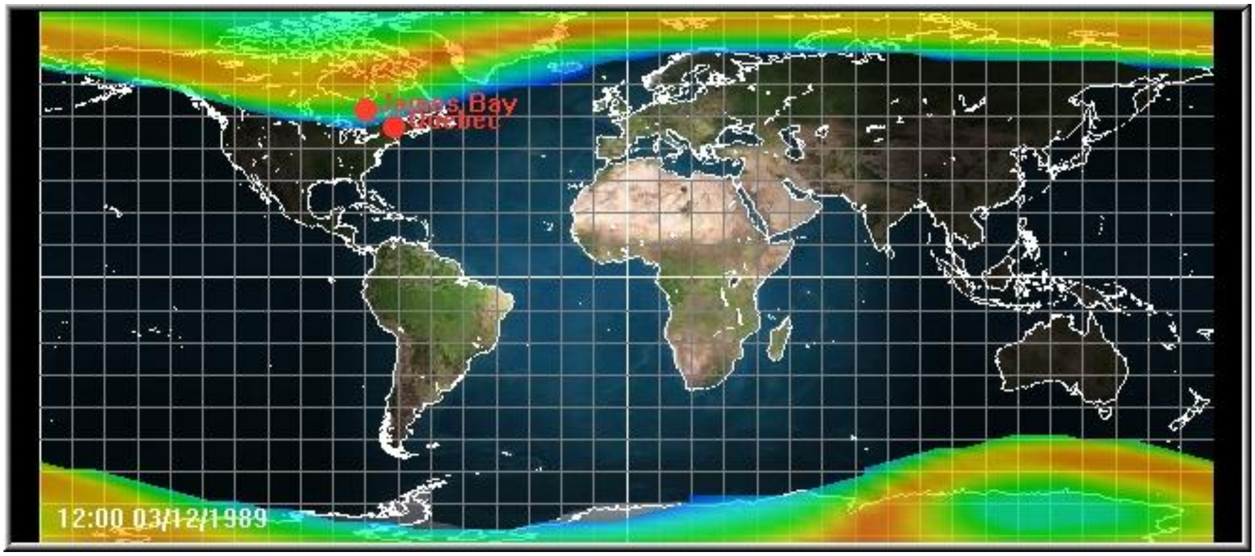
the graphic window. Move the *X* and *Y Position* sliders to a value of approximately 0.04 to make them easier to read. The graphics window should now resemble the following figure.

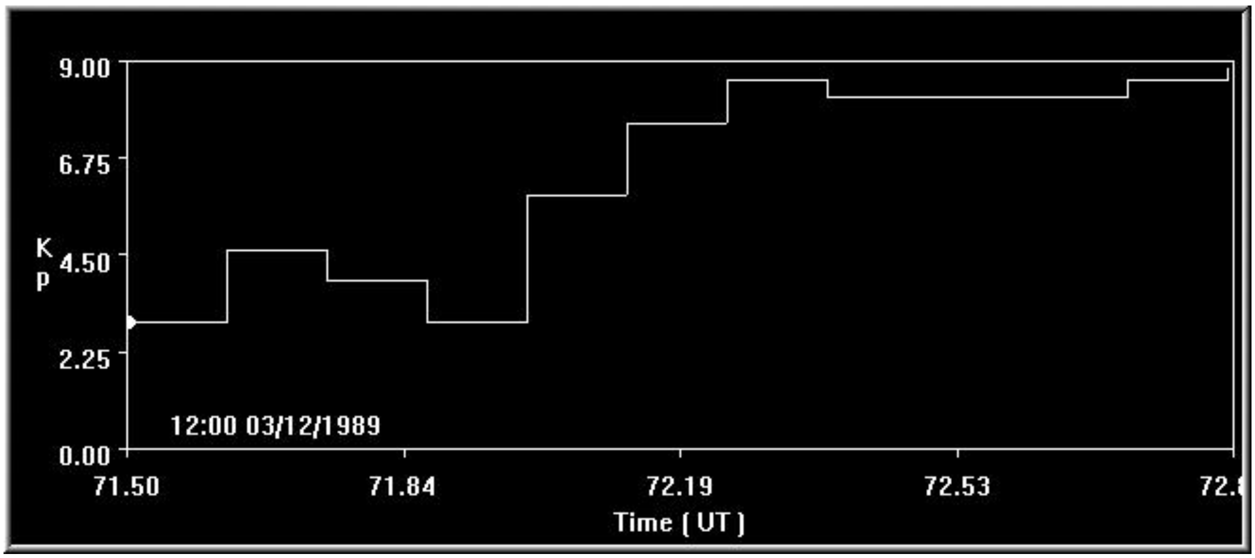


- To view the sequence of the aurora, select the *Animate Tool* option in the *Edit* menu and an *Animate* window will appear. Reset the *Time Step (sec)* text field to match the dynamic step, i.e., 10800 seconds, and click the *Update* button. Click the *Animate* check box and the time slider will advance at 10800-second increments and the 3-D graphic will update automatically. Click the *Animate* box again to stop the animation. Reset the time slider to the beginning by using the slider arrows or manually moving the slider marker to the far left.

- Use the *Viewport* menu to select *Projection* followed by *Two D* option and the 3-D window will be converted to 2-D while retaining the data display. Use the *Show Color Bar* option in the *Viewport* menu to remove the color bar. If the *Show Color Bar* feature does not respond, try highlighting the *Coord Slice* entry in the *Active Modules* list and retry the *Show Color Bar* option. Use the *Animate* window (still open) to view the changing aurora as in the last step.

- To track the Kp geomagnetic activity index used to generate this display, select the *Tile* option from the *Window* menu and the Kp vs time plot will share the graphics window space. Click in the 1-D window to activate it, highlight *Annotation* in the *Active Modules* list, and click *Display* to produces a time/date label in the 1-D window. The 1-D and 2-D windows should now display the same time/date annotation label and resemble the following figures.





- Use the *Animate* window (still open) again to follow the progression of Kp (current value is indicated by marker dot in 1-D plot) with the changing auroral precipitation. As Kp increases the aurora tends to move to lower magnetic latitudes. Note that this statistical representation of the aurora indicates that the auroral electrons extend equatorward over the James Bay and Quebec area at midnight UT of 12 March when Kp jumps to 6. The aurora remains very active in this example for the next 12 hours. Remember that the actual Hydro-Quebec power outages started occurring at 0745 UT on March 13. Note again that the model represents only a statistical pattern and, in fact, observed auroral displays were seen as far south as the Mediterranean and Japan.

This completes the Example of The Magnetic Storm of 13 March 1989 (Dynamic)

8) HELIOSpace: Loading and Viewing PARAMESH Files (Dynamic)

Note: PARAMESH data files are not generated using AF-GEOSpace, but a sample files have been provided for the purposes of this example.

The following example demonstrates the use of the *Open Paramesh* option of the *File* Menu and the graphics modules *PARAMESH-COORDSLICE, PARAMESH-FIELDLINES, PARAMESH-GRID,* and *PARAMESH-ISOCONTOUR*. These features make up the HELIOSPACE viewport extension of AF-GEOSpace.

Goal: This example demonstrates the procedure for loading and viewing MHD science code simulation results stored in large-scale structured grids using the PARAMESH file format. These visualization capabilities were developed in collaboration with the Navel Research Laboratory (NRL) for the Common High Performance Computing (HPC) Software Support Initiative (CHSSI). For more details regarding Paramesh, see the notes describing the *Open Paramesh* option in the *File* menu documentation at the beginning of this document. A sample test file set provided by NRL for this AF-GEOSpace release will enable the user to view the dynamic evolution of colliding magnetic flux tubes using the PARAMESH graphic modules appearing at the end of the graphics *Active Modules* list.

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- Establish a dynamic run by placing a check mark in the small box to the right of the *Start: UT* text field to activate the *End: Year, Day, UT* text fields. For this dynamic run, Paramesh data files will be viewed sequentially so the global time interval and parameters can be arbitrary. From the *Globals:* selector options (on the same bar as the time inputs) pick *Archive* to automatically load parameters from the NGDC archive. The global parameters for the *Start/End* interval selected can be viewed using the *Globals* menu and selecting the *Show* option. The text window that appears can be dismissed using the *Save* or *Cancel* buttons at the bottom. Note that none of these global parameters are used as inputs for this example.

Load Paramesh files,

- Choose *File* from the menu bar of the Environment Window and select the *Open Paramesh* option and an *Open* popup window will appear.

- Use the *Open* window to *Look in* the folder containing the Paramesh sample files, i.e., view the contents of $AFGS_HOME\models\data\PARAMESH\CARTESIAN\Sequence. This folder contains a *flicks.hdr* file, a *flicks.ftr* file, and a numbered set of *flicks.#####* files with one file for each time step. By default, the *flicks.hdr* file is the only one viewable with the *Open* window.

- Select the header file *flicks.hdr* in the Sequence folder and click on the *Open* button. After a few moments the *Open* window will disappear indicating that the Paramesh files have been

loaded. To confirm this, select the *Science* option in the *Module* menu and you will find a *SciNRLMHD* entry in the *Active Modules* list.

Activate a Heliospace Viewport

- Paramesh data files can only be viewed in a Heliospace viewport. To change the currently active graphics window for Heliospace displays, choose the *Viewport* menu, highlight the *Projection* submenu, and select the *HelioSpace* option. The active graphics window has now been assigned as a Heliospace viewport and can be used to display Paramesh data.

- Select the *Graphics* option in the Module menu and *Available Modules* and *Active Modules* lists will appear. To display a Heliospace label in the window, select *Annotation* from the *Available Modules* list and an *Annotation* object will be added to the *Active Modules* list. A set of Annotation Options will appear in the Environment Window. Enter "HELIOSPACE" in the *Text* box and click *Display* and a label will appear in the lower left corner of the graphic window. Move the *X* and *Y Position* sliders to a value of approximately 0.04 to improve the display.

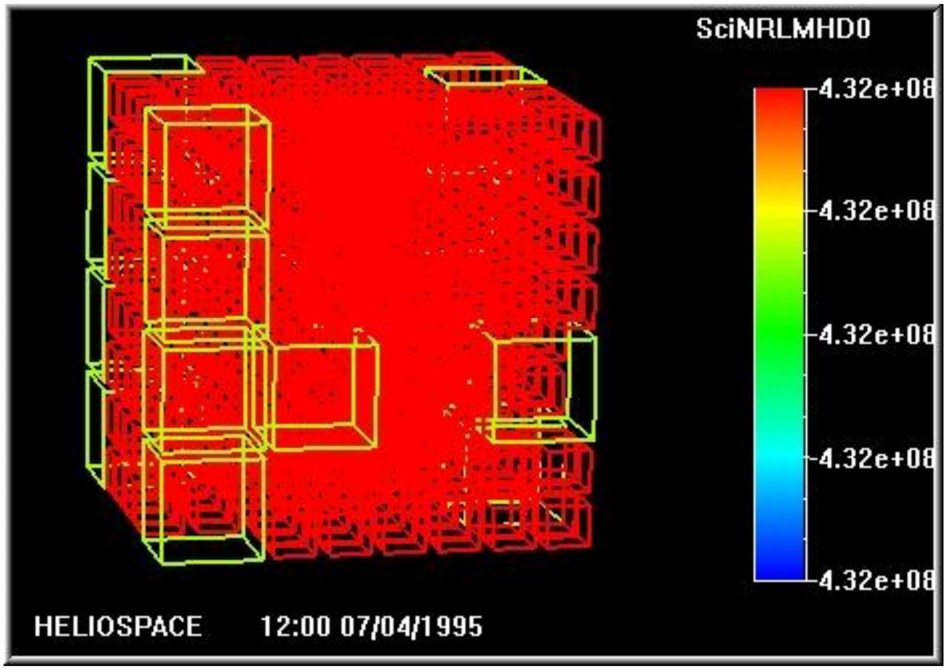
- To also display a time label in the graphics window, select *Annotation* from the *Available Modules* list and an Annotation object will be added to the *Active Modules* list. A set of Annotation Options will appear in the Environment Window. Place a check mark in the *Show Date* box and click *Display* and a time/date label will appear in the far lower left corner of the graphic window. Move the *X Position* slider to 0.4 and the *Y Position* sliders to 0.04 so that the time/date label appears to the right of the HELIOSPACE label.

Display Paramesh Grid,

- Scroll down to the bottom of the *Available Modules* list and select *ParaMesh-Grid*. A *ParaMeshGrid* object will be added to the *Active Modules* list and a ParaMesh Grid options set will appear in the environment window.

- Use the *Data* button to select the *SciNRLMHD0* option that corresponds to the Paramesh data set loaded earlier. Click the *Display* box on right side of the Para-Mesh Grid options window and a white grid cube will appear.

- Use the left/right mouse buttons to rotate/zoom in on the cube and notice that the structured grid is composed of a combination of blocks with sides of different lengths. At this point, no data are being viewed so the color scale indicates a constant value. To more easily distinguish the differently sized blocks, select the *Level* option in the Color Method input section. The graphic window should resemble the following figure.



Display a Paramesh Coordinate Slice and Isocontour,

- From the Para-Mesh Grid environment window, select the *Domain* option in the Render Blocks input section. This changes the grid into a gray colored domain background with colored x , y, and z axes represented by red, green, and blue arrows, respectively. This Grid display option is the most favorable for viewing the other Paramesh graphics objects.

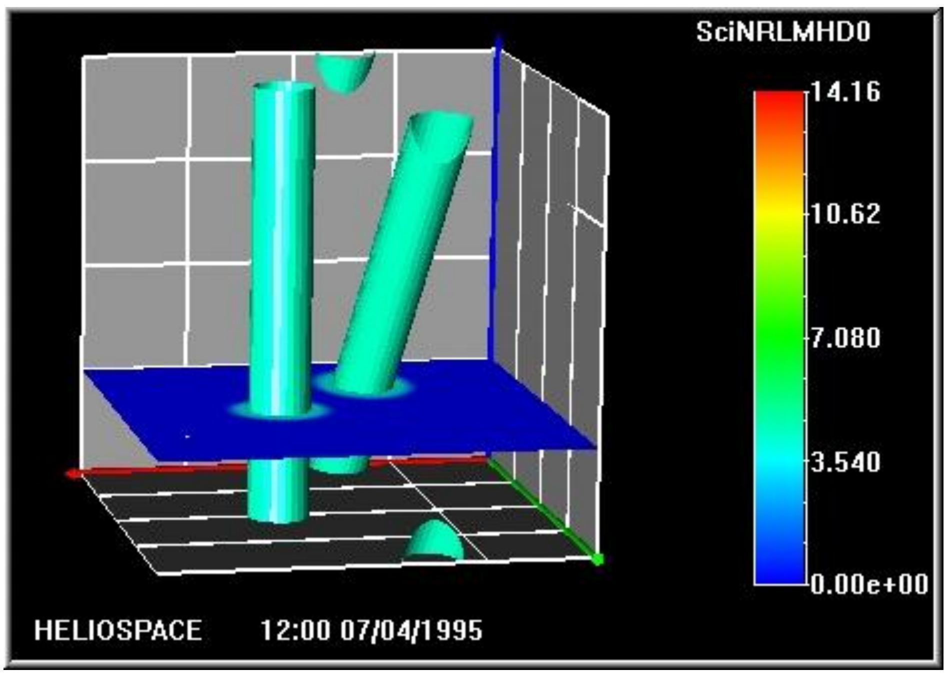
- From the *Available Modules* list select *ParaMesh-CoordSlice*. A *Pmesh Coord Slice* object will be added to the *Active Modules* list and a ParaMesh Coord Slice options set will appear in the environment window.

- Use the *Data* button to highlight the *SciNRLMHD0* option then select the *Magnetic Field* option. Click the *Display* box on right side of the Para-Mesh Grid options window and one of the domain faces, i.e., the x = 0 plane, will appear solid blue. The default Cut Plane setting of *C0* causes coordinate slices at constant x values to be displayed. Moving the *Position Value* slider between 0.0 and 1.0 will enable you to see the initial structure of the magnetic flux tubes in the domain space. The color bar now corresponds to magnetic field strength. To cut through the center of a flux tube aligned with the z-axis, move the *Position Value* slider to a value of approximately 0.375. Move the slider to approximately 0.630 to see the center of another flux tube oriented on a diagonal, as well as small portions of two other flux tubes that run parallel to the diagonal one.

- Change the Cut Plane selection to *C2* to view coordinate slices at constant z values. Move the *Position Value* slider between 0.0 and 1.0 to slide along the flux tube structures. Leave the *Position Value* slider set at approximately 0.25.

- From the *Available Modules* list select *ParaMesh-IsoSurface*. A *ParaMesh-IsoSurface* object will be added to the *Active Modules* list and ParaMesh-Isocontour options will appear in the environment window.

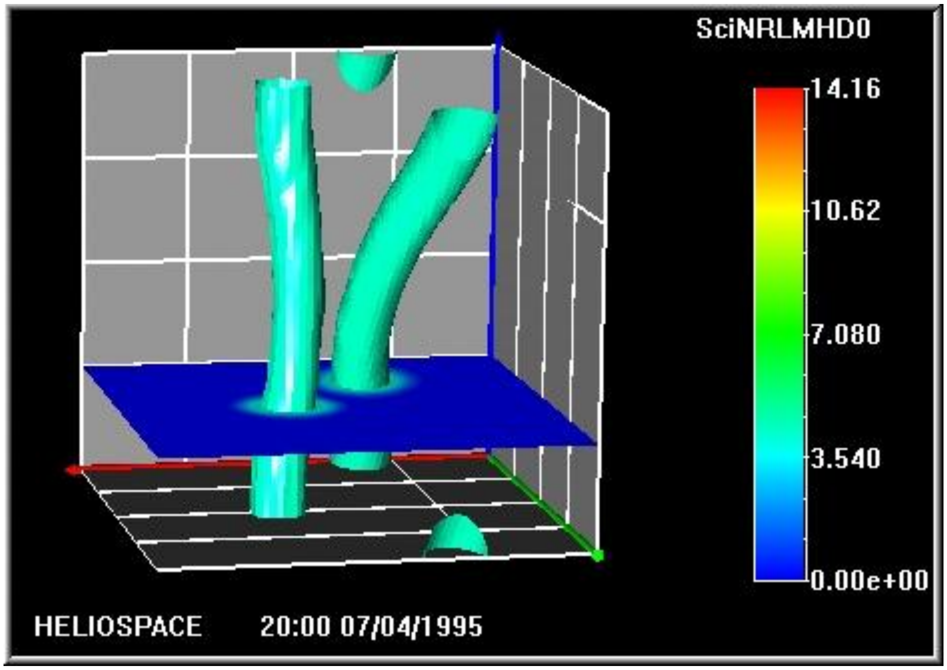
- Use the *Data* button to highlight the *SciNRLMHD0* option then select the *Magnetic Field* option. Click the *Display* box on right side of the Para-Mesh Isocontour options window and a set of flux tubes will appear in the form of isocontours. Slide the *Contour Value* slider to the right until the isocontours become blue-green (at a value of approximately 0.30). By using the left mouse button, you should be able to rotate the picture until you can see down the center of the fully-formed isocontour tubes to see the target-like pattern formed by the coordinate slice within each flux tube isocontour. With some adjustment, the Heliospace viewport should resemble the following figure.



Animate the Flux Tube Sequence,

- To view the development of the magnetic flux tubes as they collide, we will animate the isocontours. Use the *Edit* menu and select the *Animate Tool* option and an *Animate* window will appear. The animation start and end times are the default dynamic time fields from the top of the environment window. For a sequence of Paramesh data files, the file suffix numbers are used to display the simulation output in the proper order with the lowest and highest numbered files corresponding to the animation start and end times, respectively. To begin continuous animation, place a check mark in the *Animate* box under the time slider. The animate slider will progress at 900-second time steps and the magnetic flux tubes will change every four hours. Note that to get the animation time to correspond correctly with the simulation time, the proper *Start* and *End* times would need to be entered at the top of the environment window at the very beginning of this exercise. Stop the animation by clicking again in the *Animate* box. Reset the picture by moving the time slider to the far left.

- To view the sequence a single frame at a time, move the time slider manually to the right. Again, the data will be updated every 4 hours. The fourth frame of the sequence should resemble the next figure.



Prepare for viewing magnetic field lines structures,

- Turn off the coordinate slice display by highlighting the *Pmesh Coord Slice* entry in the *Active Modules* list (on the right side) and removing the check mark from *Display*.

- Reset the *Animation* window time slider to the far left position.

- Make the isocontours slightly transparent by highlighting the *ParaMesh-Isocontour* entry in the *Active Modules* list, selecting the *Transparency* option, and setting the *Transparency* slider that appears at the bottom of the window to a value of 0.25.

Display and Probe Magnetic Field Line Structure,

- From the *Available Modules* list select *ParaMesh-FieldLines*. A *ParaMeshFieldLine* object will be added to the *Active Modules* list and a Para Mesh Field Lines options set will appear in the environment window. Remove the check mark from the Start Planes *X Mid* option.

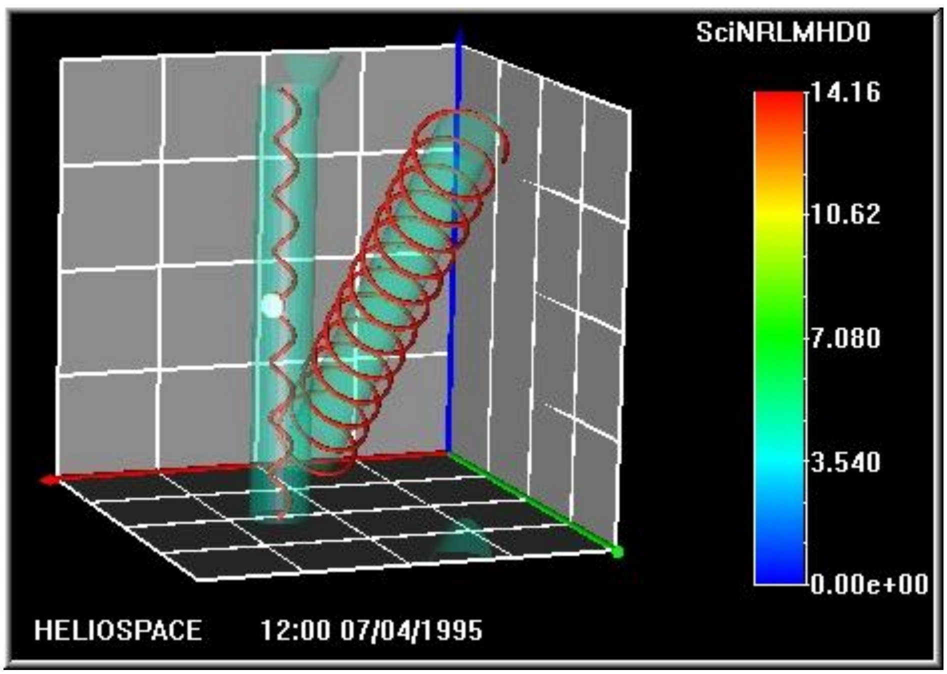
- To view single magnetic field lines, select the *User Defined* option (below the *Data* button) and the selection options will change. Use the *Data* button to highlight the *SciNRLMHD0* option and then select the *Magnetic Field* option.

- Click the *Add* button and the *Current Field Line* selector will show a *Field Line 0* entry. Click *Display* and a green dot will appear in the center of the domain. Due to the weak field

strength at this location, no field line is traced. Move the *X Position* slider to –0.3 and a field line should be visible inside the vertical flux tube.

- Click the *Add* button again and the *Current Field Line* selector will show a *Field Line 1* entry. Move the *X Position* slider to 0.45 and a field line will appear wrapped around the diagonally oriented flux tube. Use the left mouse button to rotate the graphic and view the field lines from different angles. To change the settings of either field line, use the *Current Field Line* selector to view the entry of interest and adjust the settings for that line. The tracing direction can be adjusted using the *Direction* selector near the bottom of the window. Note that these field line starting points remain fixed in space when the *Animate Tool* is used.

- To improve the appearance of the field lines, perform the following tasks: (1) set the *Line Width* selector to 2, (2) set the *Render As* selection to *Cylinders*, and (3) click the *Color* selector and click the mouse in the red part of the color wheel that appears. The Heliospace window should now resemble the following figure.



This completes the Example HELIOSpace: Loading and Viewing PARAMESH Files.

9) IONSCINT: Ionospheric Scintillation Simulation (V2.5.1 Only, Dynamic)

The following dynamic example demonstrates the use of the ionospheric scintillation simulation IONSCINT Science Module, the COORDSLICE Graphics Module, Animation, and a variety of other visualization tools.

Goal: This example exercises the IONSCINT science module for two separate time intervals. The user chooses which interval to investigate then follows the same set of steps to obtain the plots using AF-GEOSpace. In the first scenario option, we examine scintillation in the *South America* sector at one-hour intervals such that all plots are generated using a single scenario representing a single evening. As time progresses, scintillation structures appear about one hour to the East of the day/night terminator. These structures begin near the equator, grow in latitudinal extent and drift eastward with the drifting ionosphere, then begin to decay in intensity. In the second scenario, we examine the height of the scintillation season over *Africa* by looking at one-day intervals showing the high degree of day-to-day variability in scintillation produced by IONSCINT.

Start a dynamic AF-GEOSpace session and set global input parameters,

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- Establish a dynamic session by placing a check mark in the small box to the right of the *Start: UT* text field to activate the *End: Year, Day, UT* text fields. To enter the date and time inputs for the *South America* (*Africa*) scenario, edit the *Start* text fields so that *Year* = 2000 (1999), *Day* = 75 (69), and *UT* = 00:00 (21:00) and edit the *End* text fields so that *Year* = 2000 (1999), *Day* = 75 (74), and *UT* = 06:00 (21:00). From the *Globals:* selector options (on the same bar as the time inputs) pick *Archive* to automatically register the time interval and load parameters from the NGDC archive. The only global parameters that can affect IONSCINT are the Day, UT, Kp and SSN, however, in both scenarios described here we will opt for the constant input option.

Display the Earth in 2-D,

- Select the *Graphics* option in the *Modules* menu and *Available Modules* and *Active Modules* lists will appear. Select *Earth* from the *Available Modules* list. An *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear in the bottom of the Environment Window.

- Under Outline Detail select the *Textured* and *Geographic Bndys* options. Under Grid Options select the *Lat/Lon Grid* option. Click in the *Display* box to place the Earth in the default 3D window. The left and right mouse buttons can be used to rotate and scale the Earth image while the cursor is in the Window.

- From the *Viewport* menu, select *Projection* and then the *Two D* option. The graphic window containing the Earth will change to 2-D. The space to the right of the Earth graphic will be filled later with a data color bar. The center and right mouse buttons can be used to translate and scale the Earth image.

Generate Dynamic IONSCINT Data,

- Choose *Module* from the Menu Bar and select *Science* from the options. *Available Modules* and *Active Modules* lists will appear. Scroll down and select *IONSCINT* from the *Available Modules* list. A SciIonScint0 object will appear in the *Active Modules* list and IONSCINT Options will appear in the Environment Window.

- For the South America (Africa) scenario, set the Random Number Seed = -12345 (-123). Under Theater enter *Lat 1* = -40 (-20), *Lat 2* = 40 (40), *Lon 1* = 250 (-20), and *Lon 2* = 330 (60) and just below that set *Satellite Longitude* = 260 (2). In the Sunspot Number and KP input section choose the *Constant* option and enter *SSN* = 100 (100) and *Kp* = 2.0 (1.0). Select the Operational Mode called *Plume* and enter *Scintillation Intensity* = 0.5 (0.5) and *Percentile for S4 to dB Fade* = 99.5 (90.5). Note that the calculation is automatically performed on a grid with 1-degree spacing and *Grid Tool* changes will NOT alter this default.

- For the South America (Africa) scenario, we will run IONSCINT once every hour (day). Select the *Dynamic Tool* option in the *Edit* menu and a *Dynamic Tool* option window will appear. Leave the check marks in all boxes next to all four variables listed for IONSCINT, i.e., *S4Index*, *dBFade*, *ProbCom*, and *SatElev*. Edit the *Time Step (sec)* text field to read 3600 (86400) seconds and click the *Update List* button. The list in the lower part of the Dynamic Tool window should now be updated to show that IONSCINT will be run once every hour (day). Click the *Done* button to register you selections and dismiss the *Dynamic Tool* window.

- Select the *Run/Update* option in the *Edit* menu to start the calculation. A *Process View* window appears briefly. The *Model Status* window at the bottom of the Environment Window will indicate the IONSCINT run times. Because we selected the *Constant* option for specifying the SSN and Kp, the values shown in the *Model Status* window represent global archive data and will not be used in these scenarios.

Display a Time/Date Label in the Active Graphic Window,

- Select the *Graphics* option in the *Modules* menu and *Available Modules* and *Active Modules* lists will appear. Select *Annotation* from the *Available Modules* list. An *Annotation* object will be added to the *Active Modules* list and a set of Annotation Options will appear in the bottom of the Environment Window.

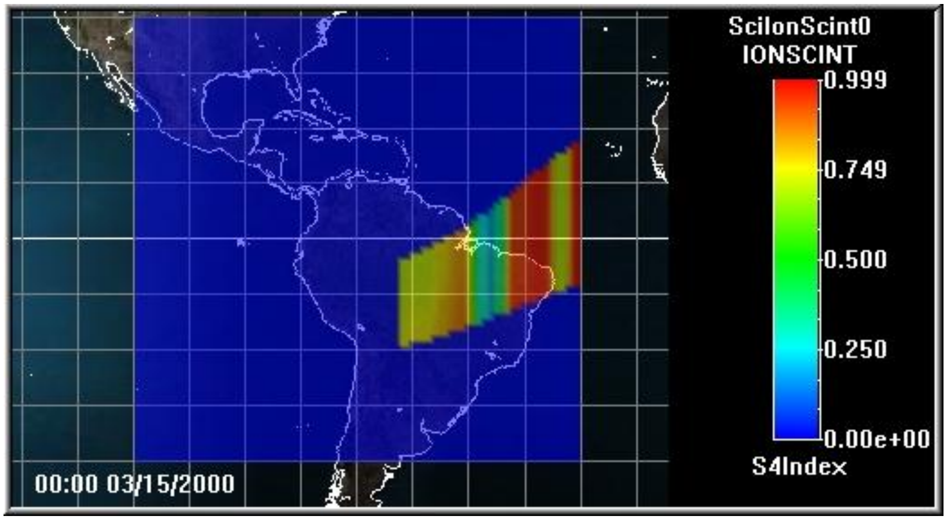
- To display a time label in the graphics window, place a check mark in the *Show Date* box and click *Display* and a time/date label will appear in the far lower left corner of the graphic window. Move the *X Position* and *Y Position* sliders to a value of approximately 0.04 to make them easier to read.

Display and Animate a Dynamic Sequence of IONSCINT Scintillation Results,

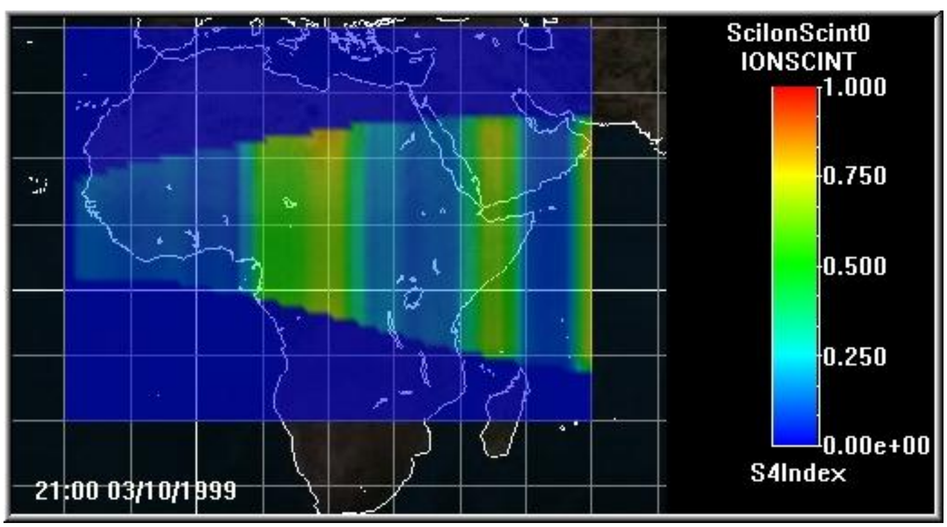
- To display the S4 scintillation index output, return to the *Available Modules* list and select *Coord Slice*. A *Coord Slice* object appears in the *Active Modules* list and a set of Coord Slice options appears in the Environment Window. Click on the *Data* button, go down to *SciIonScint0* and choose *S4Index*. Click *Display* to display the S4 Index pattern in the 2D Window.

- While the cursor is in the graphics window, use the center and right mouse buttons to translate and rescale the image, respectively, so that the theater almost fills the window. Select the *Transparency* feature on the right side of the Environment Window and move the *Transparency* slider that appears to a value of 0.50.

For the South America scenario, the graphic should resemble the following figure.

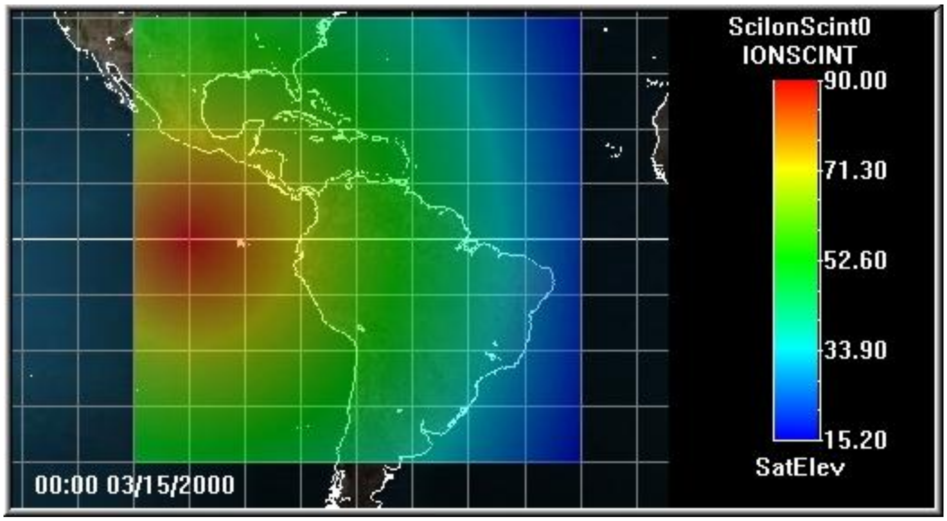


For the Africa scenario, the graphic should resemble the following figure.

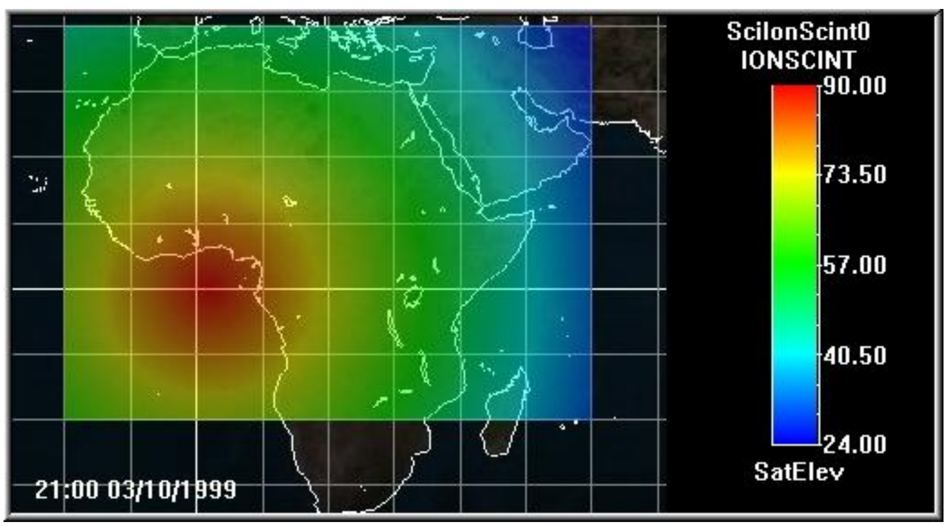


- To see the position of the geosynchronous satellite associated with this scintillation pattern, click on the *Data* button, go down to *SciIonScint0* and choose *SatElev*.

For the South America scenario, notice that the spacecraft is located directly above the geographic equator just west of South America as shown in the following figure.



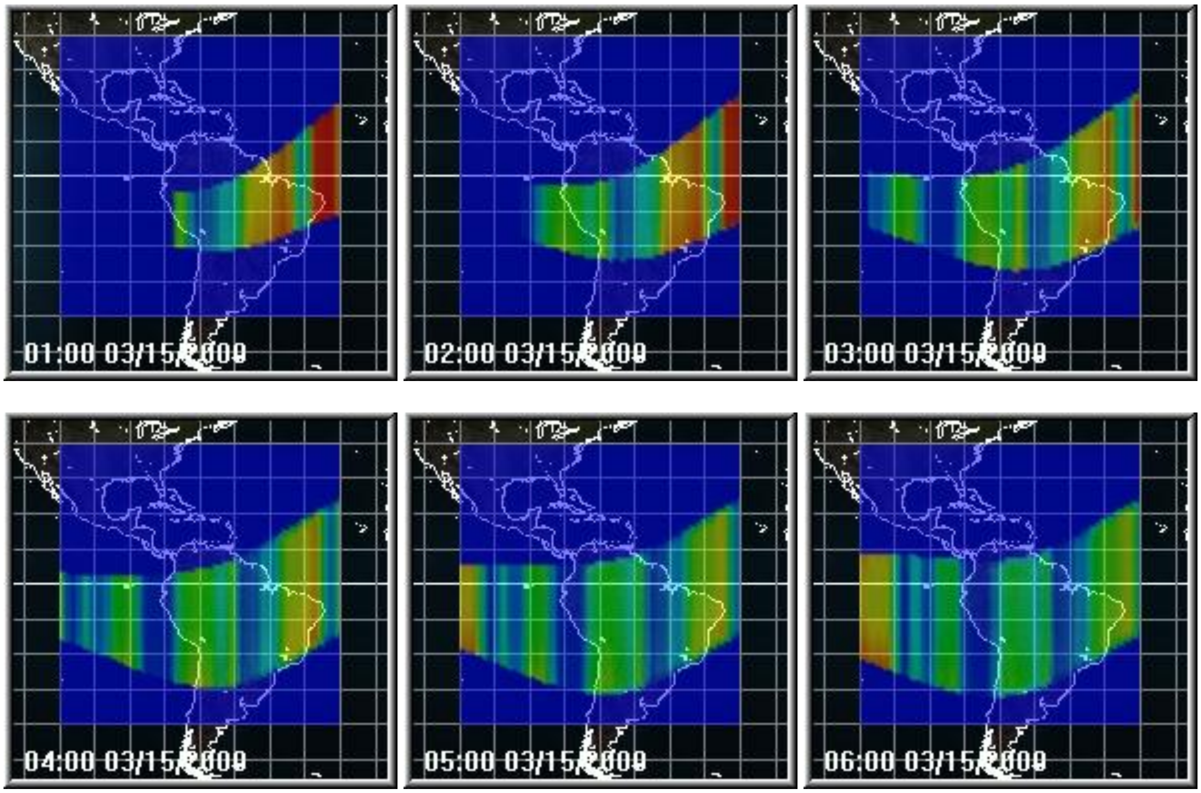
For the Africa scenario, notice that the spacecraft is located directly above the geographic equator and off the Ivory Coast as shown in the following figure.



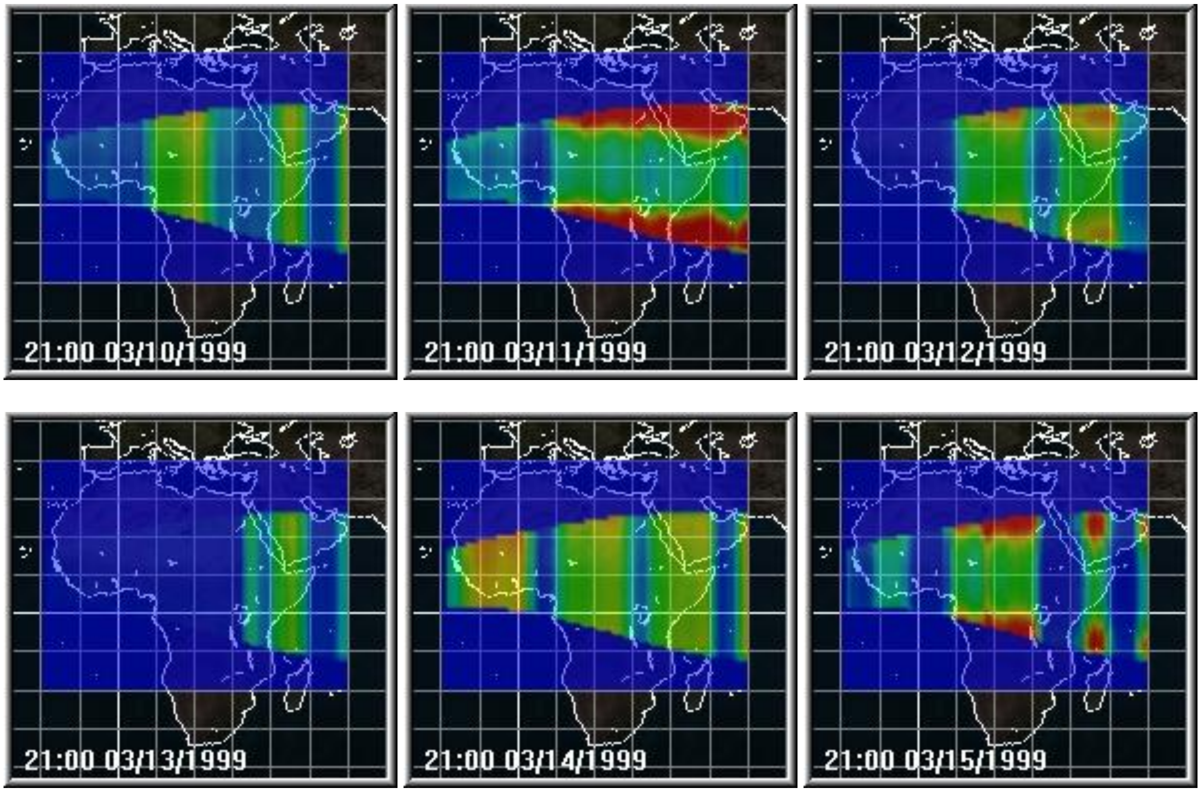
- Use the *Data* button to reset the data display to show *S4Index*. Select the *Animate Tool* option in the *Edit* menu and an *Animate* window will appear. For the South America (Africa) scenario, reset the *Time Step (sec)* text field to match the dynamic step, i.e., 3600 (86400) seconds, and click the *Update* button. Click the *Animate* check box and the time slider will advance at 3600-second (86400-second) steps and the 2-D graphic will update automatically. Note that you can change the *Data* button select while the animation is continuing to examine other parameters.

- Click the *Animate* box again to stop the animation. Manually move the time slider in the *Animate* window to the far left. Use the arrows at the ends of the slider to view the data one step at a time. The scenario sequence should resemble the following figure sets.

  South America Scenario S4Index: 01:00 – 06:00 03/15/2000 (00:00 shown above) - Scintillation structures appear about one hour to the East of the day/night terminator. These structures begin near the equator, grow in latitudinal extent and drift eastward with the drifting ionosphere, then begin to decay in intensity.



Africa Scenario S4Index: 21:00 03/10/1999 - 03/15/1999 - These plots illustrate the height of the scintillation season over *Africa* at one-day intervals and show the high degree of day-to-day variability in scintillation produced by IONSCINT.



This completes the Example of IONSCINT: Ionospheric Scintillation Simulation (Dynamic)

10) The Magnetospheric Cusp and Auroral Equatorward Boundary

The following example demonstrates the use of the AURORA Science Module, the magnetic field BFIELD-APP Module, COORD-SLICE and FIELD-LINES Graphic Modules, and a variety of other visualization tools.

Goal: Magnetospheric magnetic fields contribute to the particle precipitation patterns observed in the polar caps, i.e., the magnetic cusp is associated with a peak in ion precipitation near noon magnetic local time and plasma sheet electrons follow magnetic field lines down to the ionosphere to form the auroral oval. To illustrate these magnetic field-particle precipitation connections, the goal of this example is two-fold: (1) Examine the location of the magnetospheric cusp and its mapping as determined by several magnetic field models in relation to statistically determined auroral ion number fluxes; (2) Examine the location of the equatorward boundary of the auroral region, as determined by the electron number flux, and visualize its magnetic connection to the equatorial region of the magnetosphere.

Start an AF-GEOSpace session and set global input parameters,

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this run, set the date and time in the Environment Window by editing the text boxes to read: *Start:Year*=1993, *Day*=81, and *UT*=09:00. Select the *Archive* option using the *Globals* selector to the right of the time inputs and the values of the Kp geomagnetic index, sunspot number (SSN), F10.7 cm radio flux, and the Ap geomagnetic index for this time will be copied from archived NGDC parameters (*Kp*=4.3, *SSN*=73, *F10.7*=126.6, and *Ap*=32). Note that the modules accessed in this example will not use SSN, F10.7, and Ap.

Create and plot an aurora ion data set,

- Select the *Science* option from the *Modules* menu and *Available Modules* and *Active Modules* lists will appear. Click on *AURORA* in the *Available Modules* list. An *AURORA* object will appear in the *Active Modules* list and a set of AURORA Options will appear in the Environment Window.

- Leave the Generate, Internal B-Field, and External B-Field inputs selections as *Gridded Data*, *Centered Dipole,* and *None*, respectively. Select the *Grid Tool* option in the *Edit* menu and a *Grid Tool* window will appear. Note that the radius minimum and maximum settings are the same because the default auroral grid is a surface at ionospheric altitude. To get a smoother contour plot, increase *NPoint* in the Lat, GEOC (Deg N) section to 100 and increase *Npoint* in the Lon, GEOC (Deg E) section to 96. Hit the *OK* button to generate the grid and close the *Grid Tool* Window.

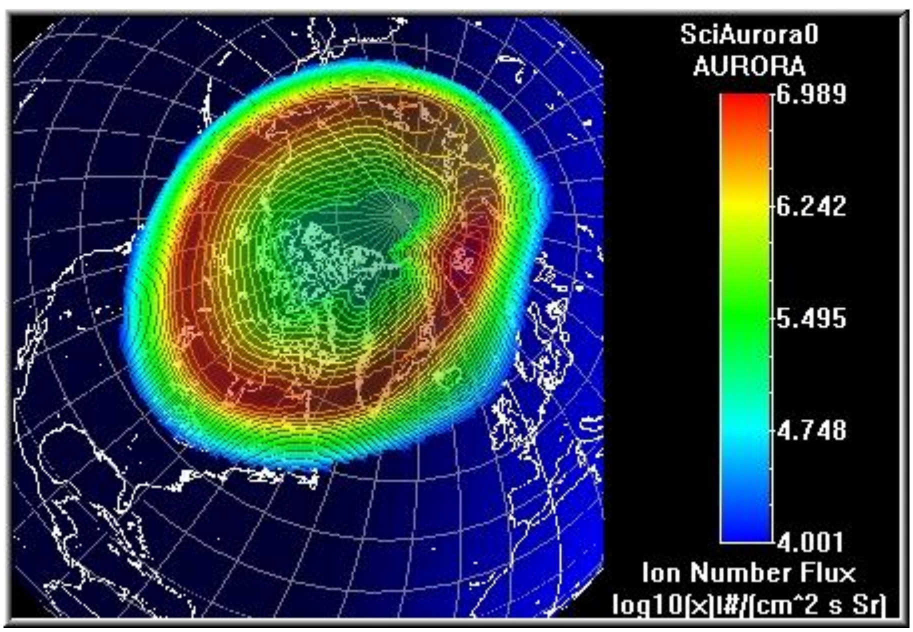
- Select the *Run/Update* option in the *Edit* menu and a *Process View* window will appear. The *Model Status* box will show the global parameters used and indicate that the model is ready after the *Process View* window disappears.

- Click on the *Modules* menu and select *Graphics*. *Available Modules* and *Active Modules* lists will appear. Select *Earth* from the *Available Modules* list. An *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear.

- Under Outline Detail leave *Geographic Bndys* checked off and under Grid Options select *Lat/Lon Grid*. Click in the *Display* box to place the Earth in the default 3-D window.

- While the cursor is in the graphic window, the left and right mouse buttons can be used to rotate and resize the view of Earth, respectively. Use the right mouse button to rescale the view so that the Earth fills a large portion of the window. Now use the left mouse button to rotate the Earth downward so you can view the North Pole.

- From the *Available Modules* list select *Coord Slice*. A *Coord Slice* object will be added to the *Active Modules* list and a set of Coord Slice Options will appear in the Environment Window. Click on the *Data* button and select *Ion Number Flux* under the *SciAurora* options list that appears. Click in the *Display* box to view the ion number flux. To make geographic features visible through the ion precipitation pattern, click the *Transparency* button and a slider appears. Move the *Transparency* slider to a value 0.80.



- To further highlight the peak flux region select the *Contours* and *Color* options in the Display Options input section and move the *Number of Contours* slider to a value of 25. Notice the flux maximum near 80 degrees geographic latitude just east of the Greenwich meridian. The corresponding maximum in the southern hemisphere appears on the coast of Antarctica at a longitude of approximately 90 degrees. The view of the northern hemisphere should resemble the figure above.

Create and plot cusp region magnetic flux tubes,

- To check the location of magnetic field model cusps relative to the ion number flux we will plot magnetic flux tubes centered about their respective magnetic cusps. If centered properly, the flux tube field lines will continue to spread as they approach the magnetopause. Some field lines will pass through the magnetic equator and connect to the opposite hemisphere while others are swept anti-sunward into the magnetotail.

- **B-field Case 1**: Return to the *Modules* menu and select *Applications*. *Available Modules* and *Active Modules* lists will appear. Select *BFIELD-APP* from the *Available Modules* list. An *AppBField* object will appear in the *Active Modules* list and B-Field Application Parameters options will appear in the Environment Window.

- Under Generate check the *Flux Tube* option (the *Gridded Data* and *MLT Field Lines* options will not be used and can be unchecked). Under Internal B-Field select the *IGRF (1945-2010)* option. Under External B-Field select the *Hilmer-Voigt '95*. Choose the *Kp Only* default option in the Hilmer-Voigt '95 Options Window that appears and click the *Done* button to dismiss the window.

- Set the Flux Tube Inputs coordinates to *Geographic* and set *Lat*=75, *Long*=21, *Alt(km)*=0, *Diam(km)*=600, and *Steps*=40. Select the *Run/Update* option in the *Edit* menu. The *Process View* window will appear momentarily and the *Model Status* box will show the dipole tilt angle (-4.1 degrees) and the Hilmer-Voigt model settings that correspond to the global Kp = 4.3, i.e., magnetopause standoff distance of 8.6 Re, Dst = -20 nT, and Eq. Edge = 59.51 degrees.

- Choose the *Modules* menu and select the *Graphics* option. *Available Modules* and *Active Modules* lists will appear. Scroll down and select *Field Lines* from the *Available Modules* list. A *FieldLines* object will appear in the *Active Modules* list and a set of Field Lines Options will appear in the Environment Window.

- Click on the *Data* button, slide down to *AppBField*, and select the *Flux Tube* option. Click *Display* to view the field lines. Click the *Color* button and use the left mouse button to click in the yellow region of the color wheel that appears so that the field lines will change from the default green color to become yellow. Select the *Smooth* Line Type option and increase the *Line Width* to 2.

- Use the right mouse button while the cursor is in the graphic window to zoom out until field lines can be seen hitting the southern hemisphere. Some field lines connect to the southern hemisphere while others hit the magnetopause. Now zoom in very close until only the footprint of the flux tube is showing and notice that the magnetic cusp in this model is centered a few degrees equatorward of the statistical ion number flux maximum shown in red in both hemispheres.

- **B-field Case 2**: Return to the *Modules* menu and select *Applications*. *Available Modules* and *Active Modules* lists will appear. Select *BFIELD-APP* from the *Available Modules* list on the

left and a second *AppBField* object will appear in the *Active Modules* list and B-Field Application Parameters options will appear in the Environment Window.

- Under Generate check the *Flux Tube* option (the *Gridded Data* and *MLT Field Lines* options will not be used and can be unchecked). Under Internal B-Field select the *IGRF(1945-2010)* option. Under the External B-Field option select the *Olson-Pfitzer "77* option.

- Set the Flux Tube Inputs coordinates to *Geographic* and set *Lat*=83, *Long*=13, *Alt(km)*=0, *Diam(km)*=600, and *Steps*=40. Select the *Run/Update* option in the *Edit* menu. The *Process View* window will appear momentarily and the *Model Status* box will show the dipole tilt angle (-4.1 degrees). Note that this model does not use the global inputs displayed, but rather represents an average quiet state of the magnetosphere.

- Choose the *Modules* menu and select the *Graphics* option. *Available Modules* and *Active Modules* lists will appear. Scroll down and select *Field Lines* from the *Available Modules* list on the left. A second *FieldLines* object will appear in the *Active Modules* list and a set of Field Lines Options will appear in the Environment Window.

- Click on the *Data* button, slide down to the second *AppBField* entry, and select the *Flux Tube* option. Click *Display* to view the field lines. Click the *Color* button and use the left mouse button to click in the very center of the color wheel so that the new field lines appear white. Select the *Smooth* Line Type option and increase the *Line Width* to 2.

- Zoom in to see that the Olson-Pfitzer model magnetic cusp is several degrees poleward of the ion number flux maximum in both hemispheres.

- **B-field Case 3**: Return to the *Modules* menu and select *Applications*. *Available Modules* and *Active Modules* lists will appear. Select *BFIELD-APP* from the *Available Modules* list on the left and a third *AppBField* object will appear in the *Active Modules* list and B-Field Application Parameters options will appear in the Environment Window.

- Under Generate check the *Flux Tube* option (the *Gridded Data* and *MLT Field Lines* options will not be used and can be unchecked). Under Internal B-Field select the *IGRF (1945-2010)* option. Under External B-Field select the *Tsyganenko '89* option. Click *OK* in the *Tsyganenko (1989) Options* window that appears to use the default *Kp Only* option.

- Set the Flux Tube Inputs coordinates to *Geographic* and set *Lat*=78, *Long*=18, *Alt(km)*=0, *Diam(km)*=600, and *Steps*=40. Select the *Run/Update* option in the *Edit* menu. The *Process View* window will appear momentarily and the *Model Status* box will show the dipole tilt angle (-4.1 degrees) and the Kp = 4-, 4, 4+ version of the model used.

- Choose the *Modules* menu and select the *Graphics* option. *Available Modules* and *Active Modules* lists will appear. Scroll down and select *Field Lines* from the *Available Modules* list on the left. A third *FieldLines* object will appear in the *Active Modules* list and a set of Field Lines Options will appear in the Environment Window.

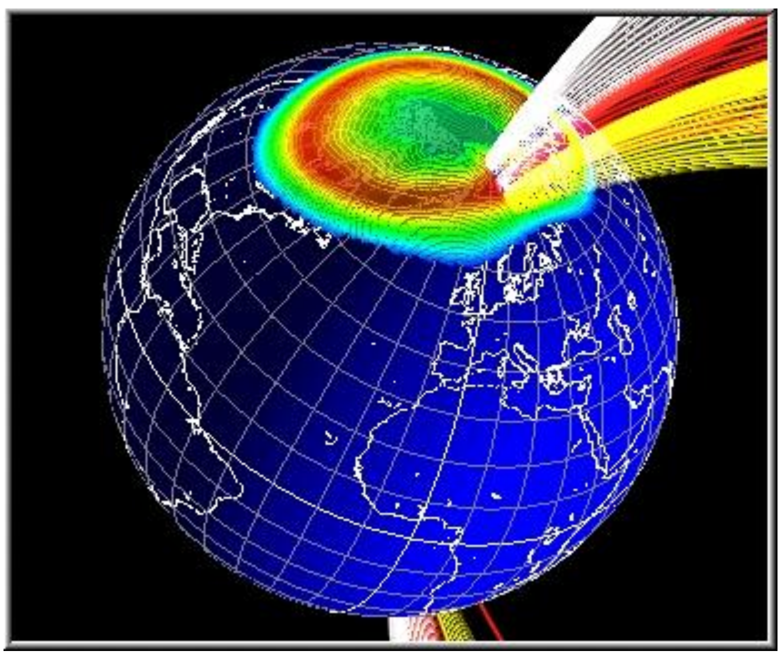
- Click on the *Data* button, slide down to the third *AppBField* entry, and select the *Flux Tube* option. Click *Display* to view the field lines. Click the *Color* button and change the new field lines to be red. Select the *Smooth* Line Type option and increase the *Line Width* to 2.

- Zoom in and notice that the Tsyganenko '89 red cusp flux tube seems centered fairly well about the ion number flux maximum.

Compare Magnetic Field Model Cusp Locations,

- Cusp comparisons can be made by using the mouse button to rotate and scale the picture while selectively turning the field-line displays on and off. Hide a set of field lines by selecting one of the *FieldLines* objects listed in the *Active Modules* list and clicking the *Display* button. Remember that the active graphic objects and the data sets are listed in the order produced: Hilmer-Voigt '95 (Yellow), Olson-Pfitzer "77 (White), and Tsyganenko '89 (Red). By viewing one set of cusp field lines at a time and selecting the *Filled Surface* Plot Type option the true funnel formed by the cusp magnetic field lines becomes more evident.

- To duplicate the next figure you must use the *Viewport* menu to uncheck *Show Color Bar* and then rotate and scale the view with the left and right mouse buttons, respectively.



Display the equatorward boundary of the aurora mapped out along magnetic field lines,

- Choose the *Science* options of the *Modules* menu and *Available Modules* and *Active Modules* lists will appear. Select *AURORA* in the *Available Modules* list. A second *SciAurora* object will appear in the *Active Modules* list and a set of AURORA Options will appear in the Environment Window.

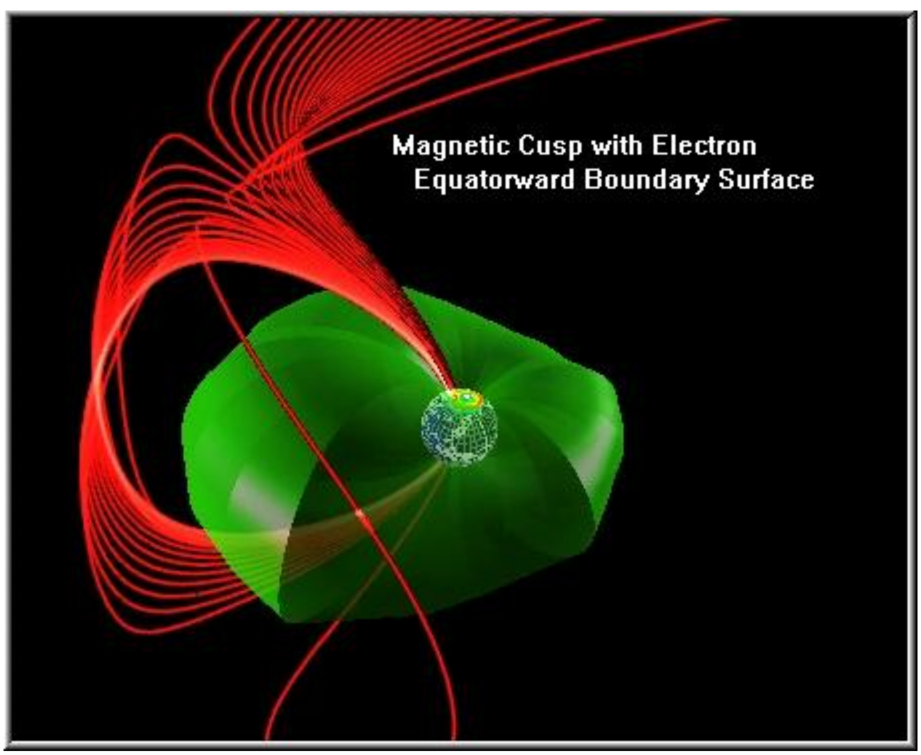
- Under Generate check the *Eq Edge* option and uncheck the *Gridded Data* option. Select the *IGRF (1945-2010)* Internal B-Field option and the *Tsyganenko '89* External B-Field option. Choose the *Kp Only* option in the *Tsyganenko (1989) Options* window that appears and click *OK*. Leave the Equatorward Edge Parameter and Model input sections unchanged.

- Select the *Run/Update* option in the *Edit* menu and a *Process Window* will appear. The *Model Status* box will show the global parameters used and indicate that the model is ready after the *Process Window* vanishes.

- Select *Graphics* from the *Modules* menu and turn off the Hilmer-Voigt (yellow) and Olson-Pfitzer (white) cusp flux tubes by removing the check mark in the *Display* box while the first and second *FieldLines* Graphics Objects are highlighted in the *Active Modules* list.

- Click on *Field Lines* in the *Available Modules* list that appears and a fourth *FieldLines* object appears in the *Active Modules* list and a set of Field-Lines Options appears. Click the *Data* button, slide down to the second *SciAurora* option listed, and select *Mapped Eq. Edge*. Click *Display* to see the field lines mapped from the electron equatorward boundary corresponding to the Kp = 4.3 global input parameter.

- To improve the picture, select the *Filled Surface* Plot Type option and remove the check mark from the *Field Lines* option. Next activate the *Transparency* option and move its slider to a value of 0.50. Now use the *Lights* option and select *Enable* (lower left of Lighting Parameters that appear) to add a diffuse lighting source. The graphic should now resemble the following figure.



- The labels were added using the annotation feature. To place a label in the active graphics window, select *Annotation* from the *Available Modules* list and an *Annotation* object will be added to the *Active Modules* list. A set of Annotation Options will appear in the Environment Window. Type the desire label in the *Text* field and click *Display*. The position of the label can be adjusted using the *X Position* and *Y Position* sliders. Two separate annotations were used for the figure above.

This completes the Example of The Magnetospheric Cusp and Auroral Equatorward Boundary.

11) Low Earth Orbit Total Dose

The following example demonstrates the use of the APEXRAD Science and Application Modules, the Satellite Application Module (SATEL-APP), the Orbit Slice and Orbit Probe Graphic Modules, and a variety of visualization tools.

Goal: View the total radiation dose distribution encountered by the low Earth orbit Defense Meteorological Satellite Program (DMSP) satellite. Contributions are from the South Atlantic Anomaly (SAA), where unusually high fluxes of inner zone particles (predominantly protons) are encountered due to the asymmetry of the Earth's magnetic field, and from the high latitude / low altitude projection of the outer radiation belt MeV electron population. (See Example 2 for an illustration of the individual electron and proton populations impacting the low Earth orbit particle environment)

Start an AF-GEOSpace session and set global input parameters,

- Initiate AF-GEOSpace via the Start menu (*Start>Programs>AFGeospace>AFGeospace*), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this run, set the date and time in the Environment Window by editing the text boxes to read: *Start:Year*=1997, *Day*=200, and *UT*=08:30. This date is consistent with the reference time of the orbit elements to be used. Select the *Globals*: *Archive* option from the selector to the right of the time inputs and the Kp, SSN, F10.7, and Ap values appear that are appropriate for this time (although they will not be used in this example).

Create APEXRAD Science Module data set,

- Select *Science* from the *Modules* menu options and *Available Modules* and *Active Modules* lists will appear. Click on *APEXRAD* in the *Available Modules* list and a *SciApexDose* object will be added to the *Active Modules* list and a set of APEXDOSE Options will appear in the Environment Window.

- Click on the *B-Model* button and select the *IGRF95* option to generate a realistically positioned South Atlantic Anomaly (SAA) for Low Earth Orbit (LEO) altitudes relatively quickly. Note that *IGRF95/O-P* model was used to construct CRRESPRO but it takes considerably longer to run. Also, while the offset-tilted dipole option *Dip-Tilt-Off* is fastest, it does not yield a realistically positioned SAA.

- Use the *Shielding* button to select *232.5 mil Al*, corresponding to the shielding thickness of the hemispheric dome number 3 of the APEX satellite.

- Leave the *Channel* button set at the default called *Total* to represent the sum of the High LET (Linear Energy Transfer) and Low LET dose channels.

- Click on the *Activity* button to see that there are several activity ranges represented (parameterized by the 15-day average Ap index), plus an average activity level for the whole mission. Select the *Whole Mission* model (default).

- Select the *Grid Tool* option from the *Edit* menu and a *Grid Tool* window will appear. Leave the default *Spacing*, *Geometry*, and *System* settings unchanged. In the Rad, GEOC (Re) section set *Npoint*=40, *Min*=1.1 Re, and *Max*=3.0 Re. In the Lat, GEOC (Deg N) section set *Npoint*=60, *Min*= -70°, and *Max*=+70°. In the Lon, GEOC (Deg E) section set *Npoint*=60, *Min*= -180°, and *Max*=+180°. Click the *OK* button to register the grid choices and close the *Grid Tool* window.

- Select the *Run/Update* option in the *Edit* menu and a *Process View* window will appear. When complete the *Process Window* will disappear and the identification and status of the model will appear in the *Model Status* box in the lower part of the Environment Window.

Create the DMSP orbit data set,

- From the *Modules* menu, select *Applications* and *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *SATEL-APP* (satellite application). An *AppSatel* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window.

- With the Element Type set as *From File*, click on the *File* button to view the *Open* window. Highlight the file "dmsp.txt" in the folder $AFGS_HOME\models\data\EPHEMERIS and click the *Open* button. Highlight *DMSPF14* in the *Current Element File* list of satellites. The orbital elements for DMSPF14 can be viewed by selecting the *Mean* option in the "Element Type" input section. Reselect the *From File* option to return to the previous view.

- The reference time *T_ref* (01/11/99, 03:43:39) and default run interval (*T_stop* - *T_start* = 1 day) are shown in the text boxes below. Leave *T_start* set at "07/19/97 8:30:00" but change the *T_stop* text box to read "07/19/97 15:30:00" to setup a 7-hour orbit run. Select the *Run/Update* option in the *Edit* menu and a *Process Window* will appear momentarily. When complete, the *Model Status* box indicates the "MODEL IS READY AND UP TO DATE."

Display the Earth, Satellite Orbit, and Time Label in 3-D,

- Select Graphics from the *Modules* menu and *Available Modules* and *Active Modules* lists will appear. Select *Earth* from the *Available Modules* list and an *Earth* object will be added to the *Active Modules* list. A set of Earth Options appears in the Environment Window.

- Select the Outline Detail options *Textured* and *Geographic Bndys*. Click *Display* and the Earth will appear in the default 3D window. The left, center (or *shift* key + left), and right mouse buttons can be used to rotate, translate, and rescale, respectively, the contents of the graphics window. Alternatively, the image orientation may be set using the *Viewport* menu (select *View Position* and then the *View…*options).

- Scroll down the *Available Modules* list and select *Satellite*. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear in the Environment Window. Pick the *Satellite* selection *DMSPF14*, click the *Label* button and select *Sat. Name*, check the *Pop Label* box, and click *Display*. The DMSP orbit (in the geocentric reference frame) will appear in the window with the satellite name (solid red circle). With no data selected, the color bar appearing reads "No Data".

- To display a time label in the graphics window, select *Annotation* from the *Available Modules* list and an *Annotation* object will be added to the *Active Modules* list. A set of Annotation Options will appear in the Environment Window. Place a check mark in the *Show Date* box and click *Display* and a time/date label will appear in the far lower left corner of the graphic window. Move the *X Position* and *Y Position* sliders to a value of 0.04.

Display and Animate Satellite and Orbit slices in 3-D and 2-D,

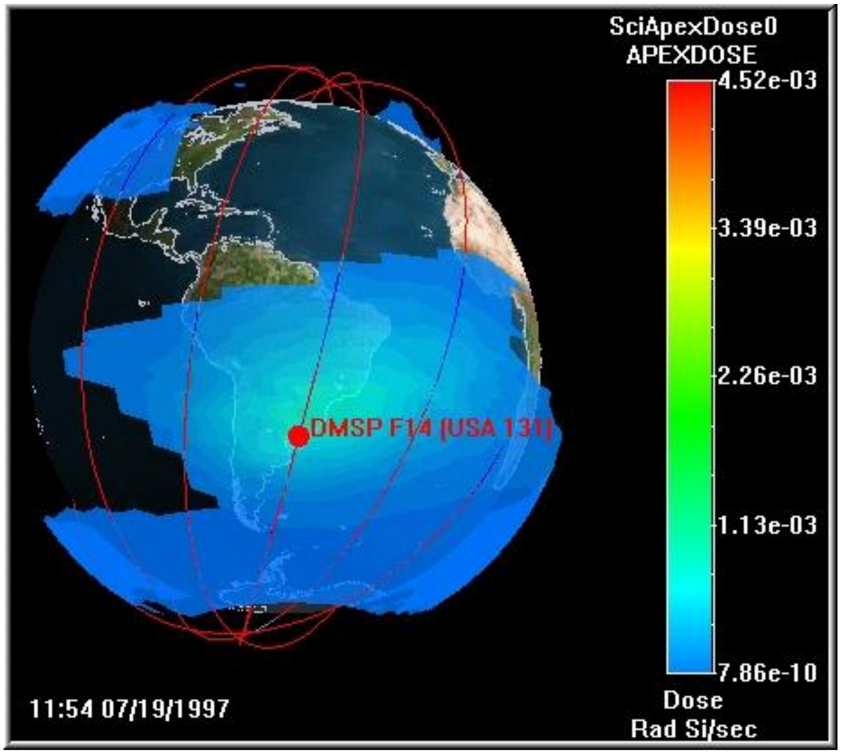
- Return to the *Available Modules* list and select *Orbit Slice*. An *OrbitSlice* Object will be added to the *Active Modules* list and a set of Orbit Slice options will appear. Pick the *Satellite* selection *DMSPF14* and click the *Data* button and select *Dose* under the *SciApexDose* option. In the Orbit Planes section, select the *P0* and *P2* options to generate data slices slaved to the satellite's radial and longitudinal positions. The coordinate geometry of the planes is determined by the *Grid Tool* selections made earlier, i.e., a spherical geographic coordinates.

- (Optional step) To improve the display appearance, click on the *Transparency* button and move the *Transparency* slider to a value of 0.80 to make the continent outlines more visible through the data. Next, click on the *Color Map* button and a *Color Map Editor* will appear. Click on the small light-blue box anchoring the left end of the blue segment and drag it downward very slightly until the dose data in the region over southeastern South American becomes greenish in color.

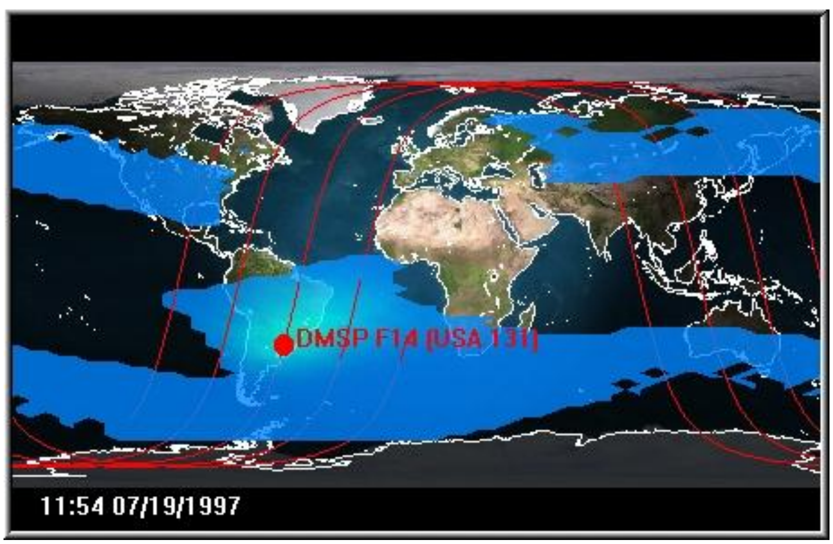
- This session is referred to as being a static one because the environment is calculated for a single time. The results of the satellite applications, however, can still be animated. Select *Animate Tool* from the *Edit* menu and an *Animate* window will appear. Edit the *Time End* text to read "07/19/97 15:30", change the *Time Step* to 360 seconds, and click the *Update* button. Click the *Animate* box and the satellite and slaved orbit slices will move at 360-second steps. Click the *Animate* box again to stop the animation.

- Reset the Animate window time slider to the far left, i.e., to 08:30. Use the time slider end arrows to forward the animation to 07/09/1997 11:54. DMSP F14 should now be directly over the South American coast in the middle of the South Atlantic Anomaly (SAA) and the graphic should resemble the next figure.

- From the *Viewport* menu, select the *Projection* then *Two D*. The viewport will change its dimensionality and retain all data. Remove the color bar to make more room by using the Viewport menu and deactivate the *Show Color Bar* option. Click the *Animate* box in the *Animate* window to move the satellite. The dose data does not change because the satellite altitude is nearly constant. You might notice that the orbit path seems to appear slightly



above and below the current satellite altitude at various times. Click the *Animate* box again to stop the animation. The graphic should resemble the following figure.



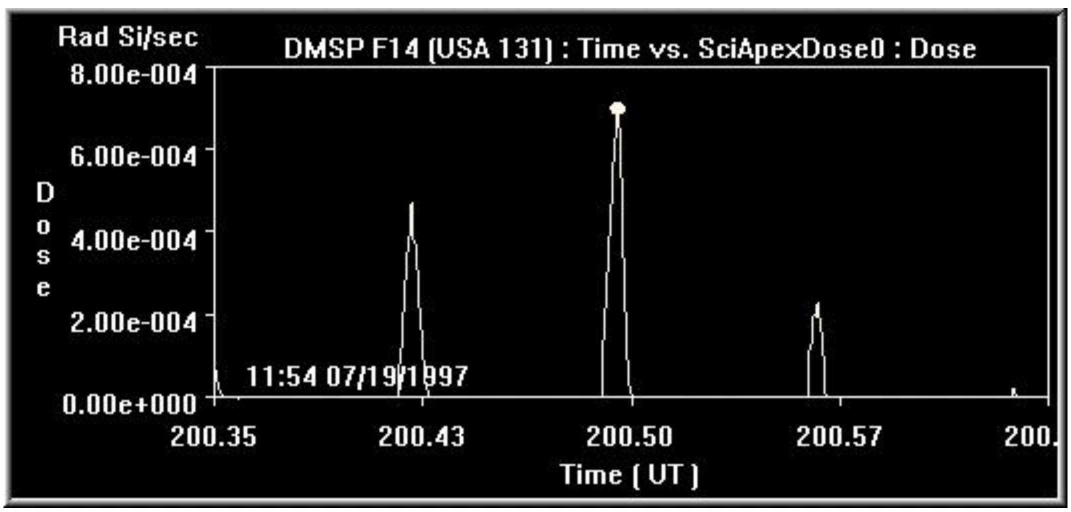
Generate a one-dimensional plot of the APEXRAD dose as seen by the DMSP satellite,

- To create a new window to display 1D results use the *Window* menu and select the *Create 1D Viewport* option. A blank graphics window with a white line just inside the frame will appear. Use the *Window* menu and select the *Tile* option to fit both open windows neatly in the available graphics window space.

- Click in the 1-D window to activate it and then highlight the *Annotation* entry in the *Active Modules* list on the left. The Annotation Options will reappear. Click *Display* and the same time/data label used in the 3-D window will appear in the 1-D window.

- Return to the *Available Modules* list on the left and select *Orbit Probe.* An *Orbit Probe* object will be added to the *Active Modules* list and a set of Orbit Probe options will appear in the Environment Window. Use the *Path/Abscissa* button to select *AppSatel* (representing the DMSPF14 satellite) and then the *Time* option. Use the *Data/Ordinate* button to select *SciApexDose* and then *Dose*. The two data selection buttons should now read "Time" and "Dose". Click *Display* and a dose vs. time plot will appear in the active 1-D window.

- The Dose values are small numbers so the y-axis labels appear as 0.00 in the default labeling format. To adjust the y-axis labels, edit the Y Axis section *Format* text box to read "%1.2e" to use an exponential format. Now reset the Y Axis section text boxes to *Min* = 0.00 and *Max* = 0.0008. Click in any other text box to register the changes. The 1-D window should resemble the following figure.



- Use the *Animate* window so that the satellite markers in both the 2D and 1D plots step along (in 360 second steps) in phase with each other as the satellite periodically encounters peak flux in the SAA. Remember that the APEX data in the 2D Window is set to track the satellite's altitude.

- (Optional) To switch the Earth plot between 2-D and 3-D, click in the 2-D window to activate it. Now use the *Projection* option of the *Viewport* menu and select *Two D* or *Three D*. This can be done while animating.

- (Optional) To see both the 2-D and 3-D plots simultaneously, maximize the 2-D window to fill the screen. Now use the *Viewport* menu to *Split* the graphic window with the *Horizontal* option. This will create two identical 2-D views stacked in the graphic window. Click in one of the graphic frames to activate it and use the *Viewport* menu to change the *Projection* to *Three D*. Use the left and right mouse buttons in the 3-D window to rotate and rescale the 3-D image. To remove one of the two visible windows, click in the frame to activate it then

select the *Delete* option from the *Viewport* menu. To find the 1-D plot again, use the *Cascade*, *Tile*, or *2:2* options in the Window menu. The last option is so named owing to the fact that the 1-D viewport was the second one created (the 1:1 option corresponds to original window which is either 2-D or 3-D depending on which steps you took above).

Run the APEXRAD Application Module to determine approximate annual doses for the specified DMSP orbit,

- Choose *Modules* from the Menu Bar and select *Applications* from the options. *Available Modules* and *Active Modules* lists will appear. Click on *APEXRAD-APP* in the *Available Modules* list and an *AppApexRad* object will be added to the *Active Modules* list. A set of Ephemeris Data options will appear. These options are similar to those used by the Satellite Application we used above.

- With Element Type left set as *From File*, click on the *File* button to view the *Open* window. Highlight the file “dmsp.txt” in the folder $AFGS_HOME\models\data\EPHEMERIS and click the *Open* button. Highlight *DMSPF14* in the *Current Element File* list of satellites. The orbital elements for DMSPF14 can be viewed by selecting the *Mean* option in the Element Type input section. Reselect the *From File* option to return to the previous view.

- The reference time *T_ref* (01/11/99, 03:43:39) and default run interval (*T_stop* - *T_start* = 1 day) are shown in the text boxes below. Select the *Run/Update* option in the *Edit* menu and a *Process Window* appears. When complete, a scrolling text window will appear with orbit-averaged dose, normalized to 1 year, for the various channels and model activities. The text window is two full pages long and will not be reproduced here. The *OK* button dismisses the text box. To redisplay it, use the *Show Text* button in the Ephemeris Data options.

This completes the Example of the Low Earth Orbit Total Dose

12) Geomagnetic Cutoff Rigidity (Dynamic)

The following example demonstrates the use of the Geomagnetic Vertical Cutoff Rigidity Interpolation Model (CUTOFF Science Module), the SATEL-APP Module, and visualization tools including the COORD-SLICE, ORBIT-SLICE, and ORBIT-PROBE Graphical Modules.

Goal: Cosmic rays are very energetic particles that penetrate the Earth's magnetic field to different depths and contribute to the radiation dose accumulated by spacecraft. The magnetic rigidity of a particle is a measure of its resistance to a magnetic field that deflects it from a straight-line trajectory. Generally, particles with higher rigidities are more likely to gain access to a given location inside the magnetosphere. The goal of this example is to examine changes in the effective rigidity of the geomagnetic cutoff along the Space Station orbit during a period of time when the geomagnetic activity was increasing, i.e., as the three-hour Kp index increased from 1+ to 8+.

Start an AF-GEOSpace session and set global input parameters

- Initiate AF-GEOSpace via the Start menu (Start > Programs > AFGeospace > AFGeospace), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- The following steps will create an 18-hour dynamic session during an interval of increasing geomagnetic activity. Set the global "Start" time parameters such that *Year*=1998, *Day*=267, and *UT*=12:00. Now place a check mark in the box to the right of the *UT* text field to designate a dynamic run (this activates the End time input fields) and set the parameters "End: Year"=1998, *Day*=268, *UT*=06:00. Click on the *Globals: Archive* option to the right of the time input fields to register the selected time interval and the corresponding set of NGDC archived global input parameter to be used during this session. View the list of inputs by selecting the *Show* option of the *Globals* pulldown menu. The *Globals* popup window shows that the value of Kp increases from 1.3 to 8.3 during the interval, i.e., from 1+ to 8+. Close the *Globals* window using the *Cancel* button.

Create an International Space Station (ISS) orbit data set

- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *SATEL-APP* (satellite application). An *AppOrbit* object will be added to the *Active Modules* list and a set of *Ephemeris Data* options will appear in the Environment Window

- Leave *From File* as the selected Element Type option. Click on the *File* button and a window will appears showing the contents of the folder $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled "iss.txt" and click the *Open* button.

- Select the one option appearing in the *Current Element File* list in the middle of the window, i.e., highlight the "ISS (ZARYA)" entry. The satellite name and the reference time (*T_ref*) associated with the orbital elements are given in boxes below the list box. To view the

orbital elements for any satellite loaded using the *From File* option, click on the *Mean* element type button. Reselect the *From File* element type button to return to the previous view. When run in dynamic mode, the start and stop times (*T_start* and *T_stop*) for the satellite are automatically set to match the time interval entered earlier.

- Select the *Run/Update* option in the *Edit* menu to create the orbit data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

Create 3D view of the Earth with an orbit trace

- Select the *Graphics* option from the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Select *Earth* from the *Available Modules* list. An *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear in the Environment Window. Select "Outline Detail" options *Textured* and *Geographic Bndys*. Click on *Display* and the Earth will appear in the default 3D graphics Window.

- Scroll down the *Available Modules* list and select *Satellite*. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear. Click the *Satellite* list and choose *ISS (ZARYA)*. Leave the *Data* button set to "No Data" and the *Label* button set to *Sat. Name*. Check the *Pop Label* option and then click *Display* and the space station orbit will appear in the 3D window.

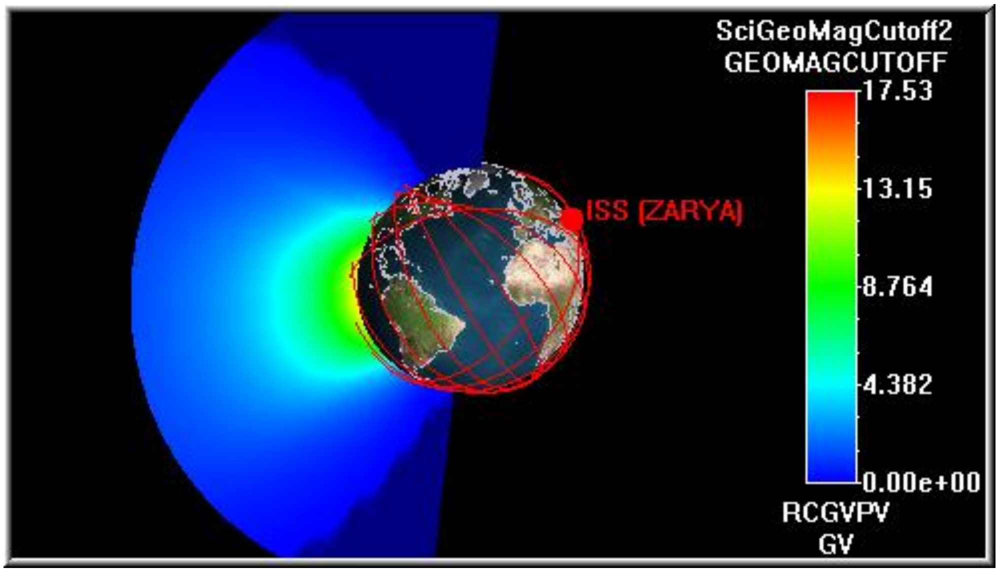
Create a Cutoff Science Module data set for the 18-hour interval

- Select the *Science* option from the *Modules* menu. *Available Modules* and *Active Modules* lists will appear. Scroll through the *Available Modules* list and click on *CUTOFF*. A *SciGeoMagCutoff* object will be added to the *Active Modules* list.

- The Geomagnetic Vertical Cutoff Rigidity Interpolation Model is driven by Kp and Time from the global parameters already registered so no other inputs are required. Because the cutoff rigidity model results are derived using both a fixed internal (IGRF 1995) and a time-dependent external (*Tsyganenko* [1989]) geomagnetic field model, the cutoff rigidity values will change with time even when Kp remains constant. To reflect this time-dependence, in the following step we will calculate model output every 6 hours, i.e., every 21600 seconds.

- Select the *Dynamic Tool* option from the *Edit* menu and the *Dynamic Tool* popup window for the CUTOFF module will appear. Place check marks in the top row of output parameters (i.e., L, INVLT, PTV, and RCGVPV), reset the *Time Step (sec)* = 21600, and click the *Update List* button. The updated window now indicates that four model runs will be performed and that the four selected parameters will be calculated for each grid point. Click the *Done* button to register these choices and to close the window. The 3D grid to be processed can be examined by selecting the *Grid Tool* option of the *Edit* menu.

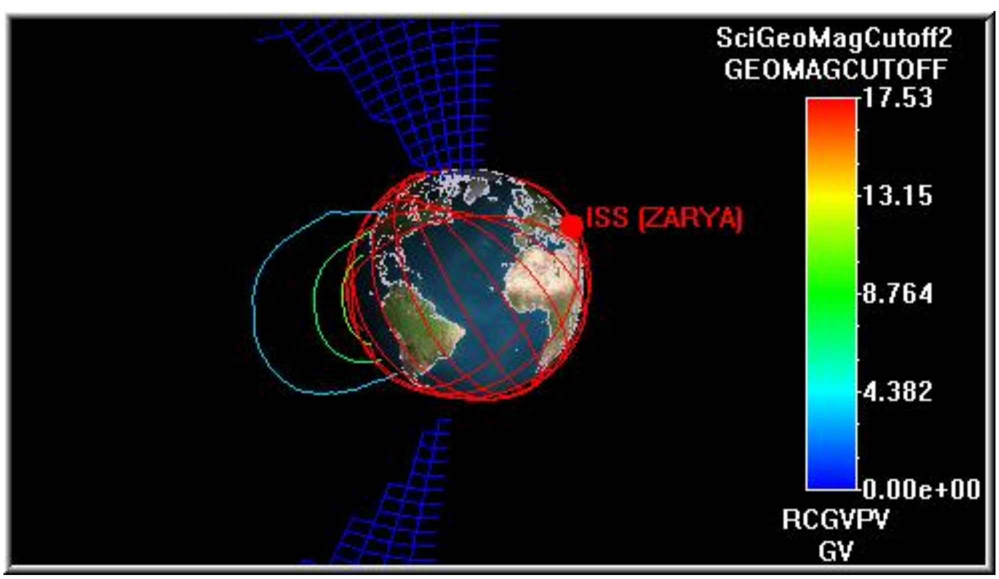
- Select the *Run/Update* option in the *Edit* menu to create the Geomagnetic Cutoff data set. When completed, the Model Status box will show the Kp values actually used at each time step and indicate that the "MODEL IS READY AND UP TO DATE."



Create a 3D view of the Effective Cutoff Rigidity

- Select the *Graphics* option from the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Select *Coord Slice* from the *Available Modules* list. A *Coord Slice* Object will be added to the *Active Modules* list and a set of Coord Slice Options will appear in the Environment Window. Click the *Data* button and select *RCGVPV* (effective cutoff rigidity in GV in the vertical direction) under the S*ciGeoMagCutoff* option. Select the *C2* Cut Plane option and select *Display* to place a constant longitude coordinate slice in the 3D window.

- Move the *Position Value* slider to longitude = -108 degrees (Position Value = 0.200). After rotating the Earth and zooming, the 3D display should resemble the figure above. This display helps to emphasize the fact that the CUTOFF Science Module covers the 3D space from low earth orbit out to beyond geostationary orbit.



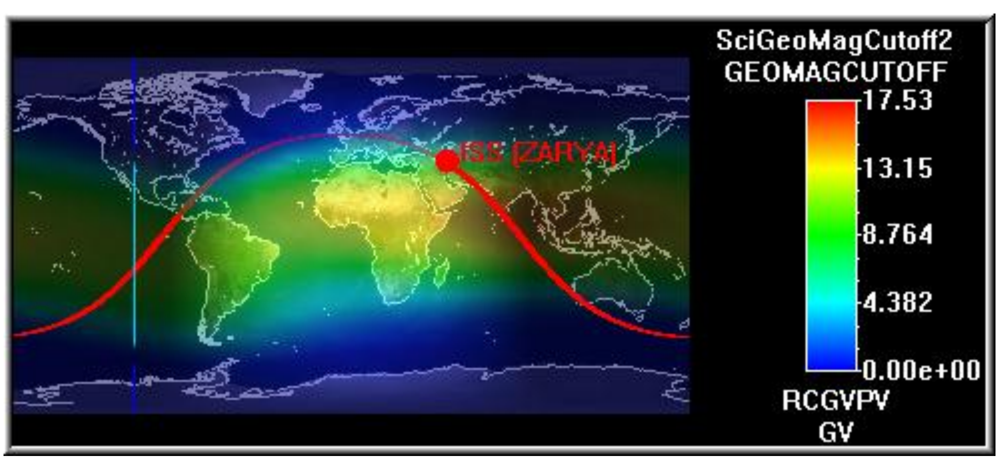
- Change the displayed filled coordinate slice to reveal colored contours at the current coordinate slice location by doing the following. In the *Display Options* section, uncheck the *Filled* option and then place check marks in both the *Contours* and *Color* option boxes. The plot should now resemble the figure above.

- Next we will animate the dynamic sequence to observe how the rigidity contours change as Kp increases (remember that Kp increases steadily with time during this interval). To animate the contours, start by opening the *Animate Tool* in the *Edit* menu. To match the step used in the Dynamic Tool earlier, set *Time Step (Sec)* = 21600 and click *Update*. Now click on the slider's right arrow to advance the time by this new time step. Note that the rigidity contours move equatorward as magnetic activity increases owing to the overall weakening of the magnetic field. Thus energetic particles typically penetrate deeper into the magnetosphere during geomagnetic storm events. Use the *Done* button to close the *Animate* window.

Create a 2D View of Rigidity at Space Station Altitude

- Scroll down the *Available Modules* list and select *Orbit Slice*. An *Orbit Slice* object will be added to the *Active Modules* list and a set of Orbit Slice Options will appear. Use the Satellite selector to pick "ISS (ZARYA)". Click the *Data* button and select *RCGVPV* (effective cutoff rigidity in GV in the vertical direction) under the S*ciGeoMagCutoff* option. Remove the check from the *Geocentric* option so as not to replot the orbit. Select the *P0* option under "Orbit Planes" (to produce a coordinate slice of constant radius slaved to the satellite's altitude) and leave the *Filled* Display Option selected. Check the *Display* button to display cutoff values. Select *Transparency* and change the slider setting to 0.5.

- Use the *Viewport* menu to select *Projection* and then its *Two D* option. All data is now project on a 2D Earth. Note that the constant longitude coordinate slice contours appear as a straight vertical line cutting through the Americas. Return to *Active Modules* and highlight *Satellite*. Under "Reference Frame", uncheck *Geocentric* and select *Inertial*. Highlight the *Coord Slice* entry in the *Active Modules* list to refresh the color bar label. The 2D window should resemble the figure below. Note that you can get back to a 3-D view by using the *Projection* option of the *Viewport* menu and select *Three D*.

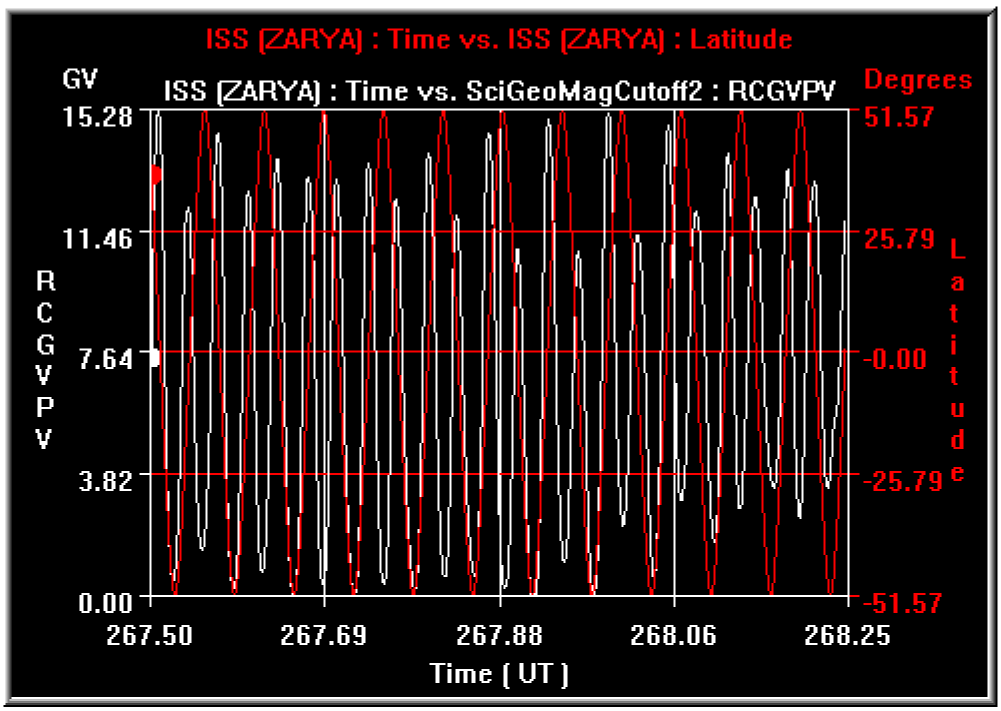


Display a 1D Rigidity data set along the ISS orbit track

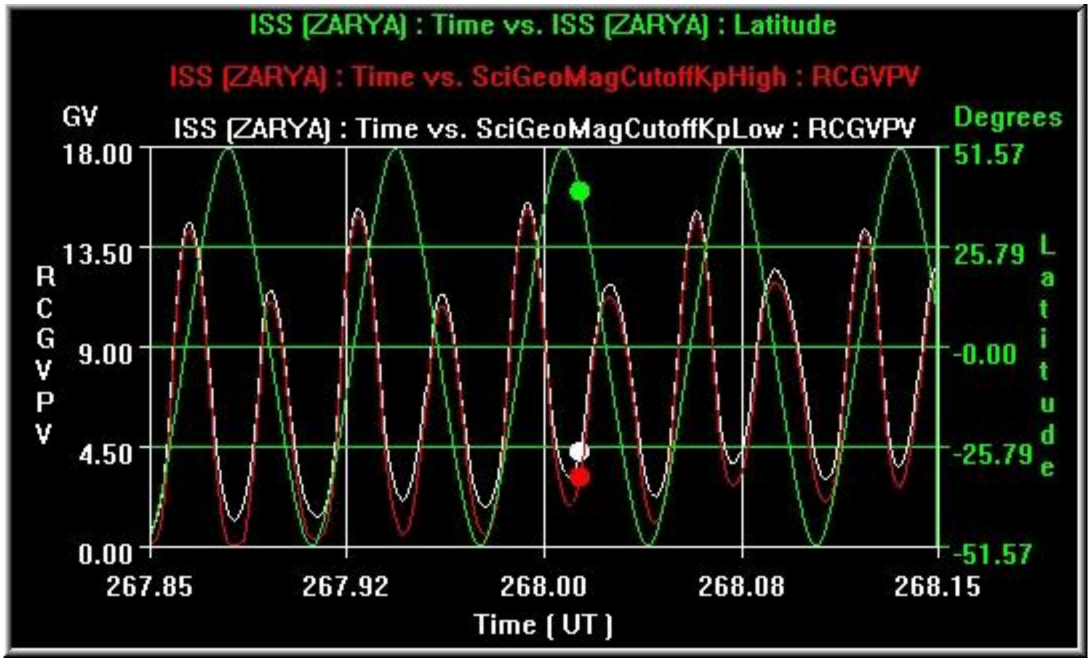
- Use the *Window* menu to select *Create 1D Viewport* and an empty 1-D graphics window will appear. Note that the *Window* menu options *Cascade* and *Tile* can be used to access the existing original 3-D window.

- Scroll through the *Available Modules* list and click on *Orbit Probe*. An *Orbit Probe* object will be added to the *Active Modules* list and an Orbit Probe Option Panel will appear in the Environment Window. Click on the *Path/Abscissa* button and select the *Time* option under *AppOrbit*. Click on the *Data/Ordinate* button and select the *RCGVPV* option under *SciGeoMagCutoffKp*. Click *Display* and a plot of RCGVPV vs. Time for the ISS orbit will appear.

- Click on *Orbit Probe* in the *Available Modules* list again. A second O*rbit Probe* object will be added to the *Active Modules* list. Click on the *Path/Abscissa* button and select the *Time* option under *AppOrbit*. Click on the *Data/Ordinate* button and select the *Latitude* option under *AppOrbit.* Click *Display* and a plot of Latitude vs. Time for the ISS will appear. In the *Y-axis* Options section, select the *Right* button to move the labels to the other side of the plot. Remove the redundant x-axis by removing the check from the X Axis *Enabled* box. The 1D plot should now resemble the next figure.



The final figure below (not generated as part of this example) was made using the *Orbit Probe* module and shows the RCGVPV parameter along the ISS orbit when Kp is held constant at Kp = 1.3 (red line) and Kp = 8.3 (white line). The cutoff values (in GV) peak near the geomagnetic equator and are larger for the low Kp case, i.e., the overall geomagnetic field values are stronger for this case and thus particles need more energy to penetrate to those locations. The RCGVPV curve in the figure above would fall between the red and white curves in the figure below.



This completes the Example of the Geomagnetic Cutoff Rigidity

13) Meteor Impact Hazards

The following example demonstrates the use of the Meteor Impact Science Module, the Meteor Sky Map Science Module, the Meteor Impact Application Module and a variety of visualization tools.

Goal: View the meteor flux and counts of two coincident meteor showers with a user-defined storm inserted in both 2D and 3D. Fly a satellite through the meteor environment and create a 1D plot of meteor flux along the satellite path that includes the cumulative impact probability.

Start an AF-GEOSpace session and set global input parameters

- Initiate AF-GEOSpace via the Start menu (Start > Programs > AFGeospace > AFGeospace), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this static run, set the Global Parameters as follows: *Start:Year*=1995, *Day*=225, *UT*=12:00. Click on the *Globals: Archive* option to the right of the time input fields to automatically load the set of NGDC parameters for this time (*Kp*=2, *SSN*=9, *F10.7*=72.7, and *Ap*=7).

Create the DMSP orbit data set

- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *SATEL-APP* (satellite application). An *APPOrbit* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window

- Leave the *From File* Element Type option selected and click on the *File* button and a window will appears showing the contents of the folder $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled "dmsp.txt" and click the *Open* button.

- A list of DMSP satellites will appear in the *Current Element File* list in the middle of the window. Select *DMSP F8 (USA 26).* The satellite name and the reference time associated with the orbital elements are given in boxes below the list box. To view the orbital elements for any satellite loaded using the *From File* option, click on the *Mean* element type button. Reselect the *From File* element type button to return to the previous view. The default value for the start time ("T_Start") is taken from the global values at the top of the Environment Window. Whenever a SATEL-APP module is run in "static" mode, a 1-day interval with a 60-second time step is used by default.

- Select the *Run/Update* option in the *Edit* menu to create the orbit data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

Create 2D view of the Earth with an orbit trace

- Select the *Graphics* option from the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Earth*. An Earth object will be added to the *Active Modules* list and a set of Earth Options will appear in the Environment Window. Select "Outline Detail" options *Textured* and *Geographic Bndys*. Click on *Display* and the Earth will appear in the Window. Convert the image to 2D by using the *Viewport* menu to select *Projection* and then its *Two D* option (note that the *Three D* option can be used to convert it back to a 3D window).

- Scroll down the *Available Modules* list and select *Satellite*. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear. Click the *Satellite* list and choose *DMSP F8*. Under "Reference Frame", check *Inertial (ECI)* and uncheck *Geocentric (GEOC)*. Click in the *Display* box and the DMSP orbit will appear.

Create a Meteor Impact Science Module data set

- Select the *Science* option from the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll through the *Available Modules* list and click on *METEOR IMPACT*. A *SciMeteorImpact* object will be added to the *Active Modules* list and Meteor Impact Map options will appear in the Environment Window. In the Show Simulation section, the *Sporadics* and *Flux Only* options should be selected.

- Within the optional Storm Simulations section, change the "Shower Name" to *delta-Aquarids(S) (185-232)*. With the *Date/Duration* button selected, change the storm duration by setting "Duration (Hr)"= 6.00. Click the *Add* button to register the item in the *Storms* list.

- Select the *Run/Update* option in the *Edit* menu to create the Meteor Impact data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

Create a 2D view of Meteor Flux

- Select the *Graphics* option from the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Select *Coord Slice* from the *Available Modules* list. A *Coord Slice* Object will be added to the *Active Modules* list and a set of Coord Slice Options will appear in the Environment Window.

- Click the *Data* button and select *Meteor Flux* under the *SciMeteorImpact* option. Select *Display* to produce a fixed radius coordinate slice (corresponding to the default Cut Plane *C0*).

- Click the *Transparency* button on the right side of the environment window and a *Transparency* slider will be displayed at the bottom of the window. Change the slider value to 0.7 so the continent outlines can be seen. Resize the window so it resembles the following figure.

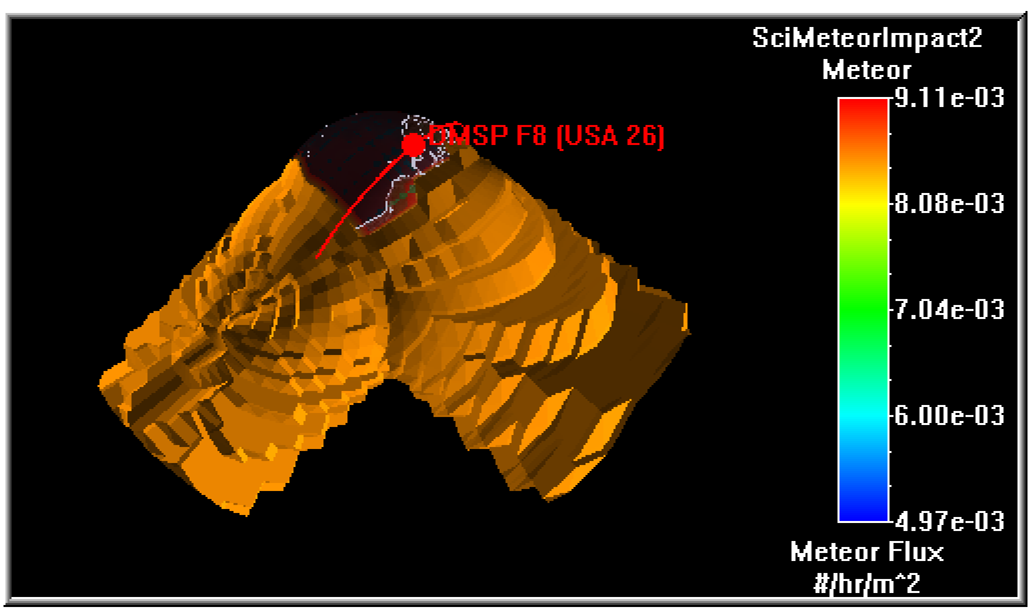
Create a 3D view of Meteor Flux

- Use the *Viewport* menu to select *Projection* and then its *Three D* option. Return to *Available Modules* and click on *Isocontour*. An *IsoContour* Object will be added to the *Active Modules* list and a set of Isosurface Options will appear.

- Click the *Data* button and select *Meteor Flux* under the *SciMeteorImpact* option. Click *Display* and move the *Contour Value* slider to 0.859. After rotating the image, Isosurfaces for two showers from different directions will appear as in the next figure.

Create a 2D Meteor Sky Map Science Module data set

- Select the *Science* option from the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll through the *Available Modules* list and click on *METEOR SKY MAPS*. A *SciMeteorMap* object will be added to the *Active Modules* list and Meteor Ground Based Sky Map and Storm Simulation options panels will appear in the Environment Window. The *Visual* and *Sporadics* options should already be selected.



- Within the Storm Simulations section, change the "Shower Name" to *delta-Aquarids(S) (185-232)*. With the *Date/Duration* button selected, change the storm duration by setting "Duration (Hr)"= 6.00. Click the *Add* button to register the item in the Storms list.

- Select the *Run/Update* option in the *Edit* menu to create the Meteor Impact data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

Create a view of the Meteor Sky Map

- Use the *Window* menu to select the *Create 2D Viewport* option and a new 2D window will appear. Select the *Graphics* option from the *Module* menu and *Available Modules* and *Active Module*s lists will appear. From the *Active Modules* list, highlight *Earth* and click *Display*. To show the orbit already generated, highlight the *Satellite* entry in the *Active Modules* list and click *Display*.

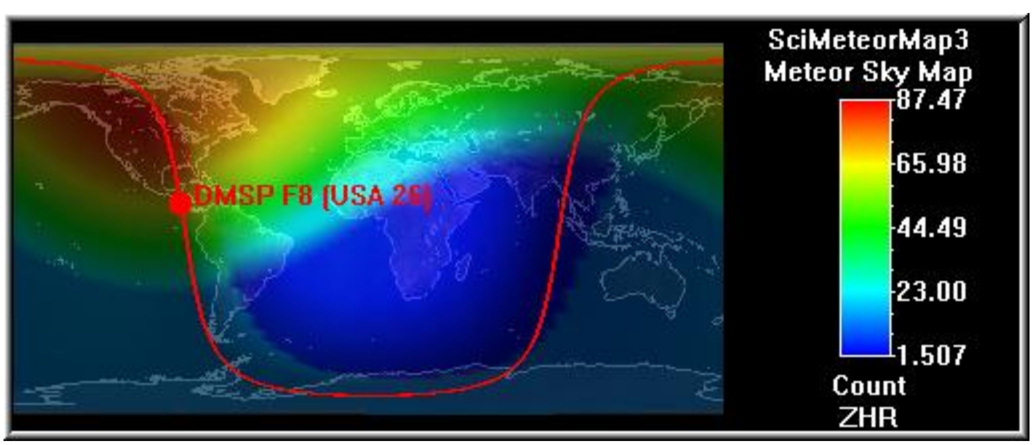
- Scroll up the *Available Modules* list and select *Coord Slice* and a Coord Slice entry will appear in the *Active Modules* list. Click the *Data* button and select *Count* under the *SciMeteorMap* option and click *Display*. After using the *Transparency* option to set a transparency value of 0.75, the 2D plot should resemble the figure below.

Create a Meteor Impact Application data set.

- Select the *Applications* option from the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll through the *Available Modules* list and click on *METEOR IMPACT APP*. An *AppMeteorImpact* object will be added to the *Active Modules* and a Meteor Impact Application and Storm Simulation options panels will appear in the Environment Window.

- Within the Storm Simulations section, change the "Shower Name" to *delta-Aquarids(S) (185-232)*. With the *Date/Duration* button selected, change the storm duration by setting "Duration (Hr)"= 6.00. Click the *Add* button to register the item in the *Storms* list.

- Under Meteor Impact Application Options, select *Setup* option *Satellite* to see satellite options. With the *From File* element type option selected, click on the *File* button and a



window will appear showing the contents of $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled "dmsp.txt" and click the *Open* button.

- A list of DMSP satellites will appear in the *Current Element File* list in the middle of the window. Select *DMSP F8* and edit the text boxes so that "T_start" reads "08/10/95 12:00:00.00" and "T_stop" reads "08/17/95 12:00:00.00". Select the *Run/Update* option in the *Edit* menu to create the orbit data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

Display a Meteor Impact Application data set

- Use the *Window* menu to select the *Create 1D Viewport* option and an empty 1-D graphics window will appear. Note that the *Window* menu options *Cascade* and *Tile* can be used to access the existing original 3-D window.

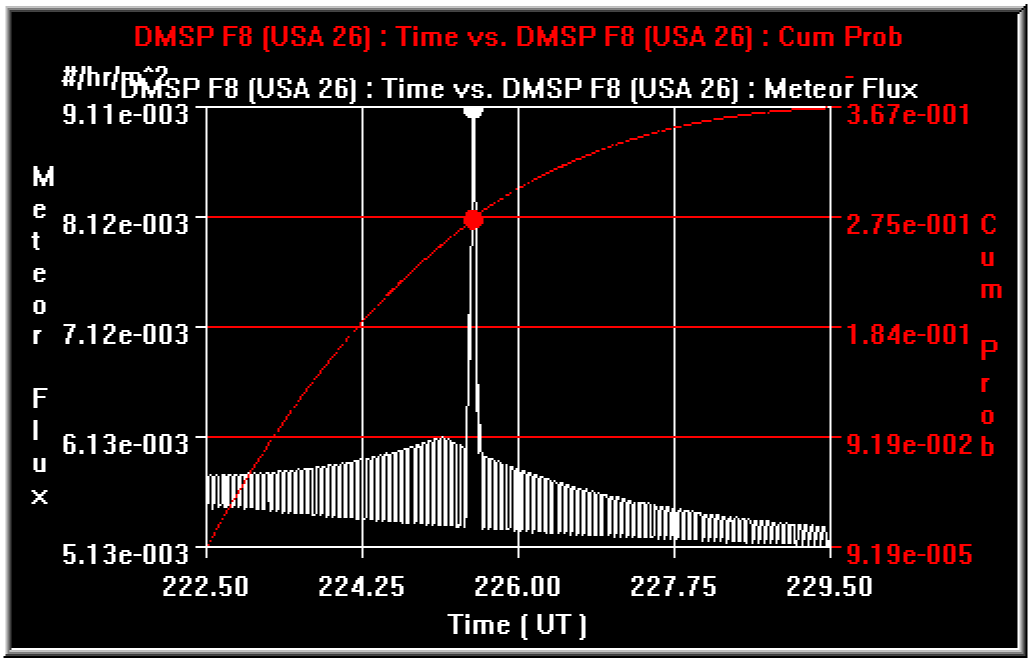
- Select the *Graphics* option from the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll through the *Available Modules* list and click on *Orbit Probe*. An *OrbitProbe* object will be added to the *Active Modules* list and an Orbit Probe options will appear in the Environment Window.

- Click on the *Path/Abscissa* button and select the *Time* option under *AppMeteorImpact* (*AppOrbit*). Click on the *Data/Ordinate* button and select the *Meteor Flux* option under *AppMeteorImpact*. Click *Display* and a plot of Meteor Flux vs. Time (along the DMSP orbit) will appear.

- In the *X-Axis* Options section, change the information in the *Format* text box to read %1.2f. Click in any other text box to register the change.

- Click on *Orbit Probe* in the *Available Modules* list again. A second *OrbitProbe* object will be added to the Active Modules list. Click on the *Path/Abscissa* button and select the *Time* option under *AppMeteorImpact*. Click on the *Data/Ordinate* button and select the *Cum Prob* option under *AppMeteorImpact*. Click *Display* and a plot of Cum Probability vs. Time (along the DMSP orbit) will appear.

- In the *X-axis* Options section, uncheck the *Enabled* option. In the *Y-axis* Options section, select *Right*. The 1D plot should now resemble the figure below, which shows how the shower gradually grows and wanes in intensity over the seven day period. The optional storm inserted appears as a spike centered on the global time of 12:00 on day 225. The red line represents the cumulative probability of a meteor strike.



This completes the Example of Meteor Impact Hazards.

14) DMSP Precipitating Particles: Data vs. Climatology

The following example demonstrates the use of the DMSP Data Module, the DMSP Graphics Module and the Spectral Viewport, the AURORA Science Module, the Satellite Application Module (SATEL-APP), and the Orbit Probe Graphic Module.

Goal: View DMSP precipitating electron and ion data using energy versus time spectral plots. For the same orbit, create a 1D plot comparing the observed electron integral number flux along a DMSP orbit with that specified by the Hardy Aurora model.

Start an AF-GEOSpace session and set global input parameters

- Initiate AF-GEOSpace via the Start menu (Start > Programs > AFGeospace > AFGeospace), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this static run, set the Global Parameters as follows: *Start:Year*=2003, *Day*=94, *UT*=00:00. The Kp index and other parameters corresponding to the specified date and time may now be obtained by clicking on the *Globals: Archive* option to the right of the time input fields. The NGDC archived values of these parameters are then automatically loaded (*Kp*=4.3, *SSN*=72, *F10.7*=148.8, and *Ap*=32).

View 2-D Energy Spectra Plots of DMSP Data

- Select the *Data* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Select *DMSP* from the *Available Modules* list. An *AppDmsp* object will be added to the *Active Modules* list and a set of DMSP Options will appear in the Environment Window. Use the *Satellite* selector and choose *All* (so all available data files will eventually be displayed). The next step will be to locate the sample DMSP data sets supplied with the AF-GEOSpace software.

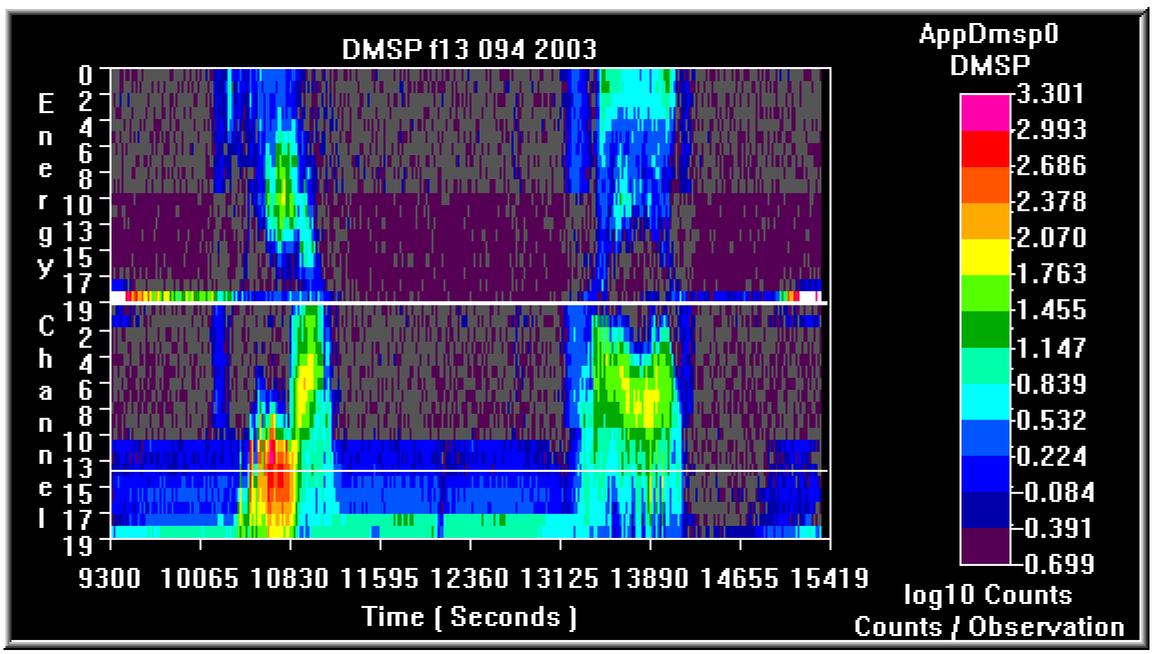
- There are two methods of accessing DMSP data: (1) If *$AFGS_HOME\bin\AFGeospace.bat* was edited before this AF-GEOSpace session to define the environment variable associated with the DMSP data, then a selection of files with names of the form "j4f1303###" appeared in the environment window during the previous step (see note in section "The DMSP Data Module" of this document), or (2) if the DMSP environment variable was not previously set, then select the *Browse* button to locate this data. The *Browse* button will call up an *Open* window. Use it to look inside the directory *$AFGS_HOME\models\data\DMSP\2003*, highlight one of the files, select the *Open* button, and five file names of the form "j41303###" will appear in the environment window.

- The five entries now appearing in the environment window represent five days of DMSP-F13 data for days 92 to 96 of year 2003. Highlight entry *j41303094* and change the *Orbit Number (1-15)* selector to read *3*. These settings will process data from the SSJ/4 sensor of DMSP-F13 orbit 3 of day 94 of 2003. Use the *Run/Update* option of the *Edit* menu to prepare the selected DMSP data for viewing. The status bar at the bottom of the environment window

will indicate when the data is “Ready”. Now that the DMSP data is ready, we next need to access the DMSP Graphics Module.

- Select the *Graphics* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Select *DMSP* from the *Available Modules* list. A *2D Plot* object will be added to the *Active Modules* list and a set of DMSP Options will appear in the Environment Window. Now use the *Data* button to select *Counts* under *AppDmsp* option and notice that the *Display* options remains inactive. This is because the display of 2D spectral data requires use of a special spectral window.

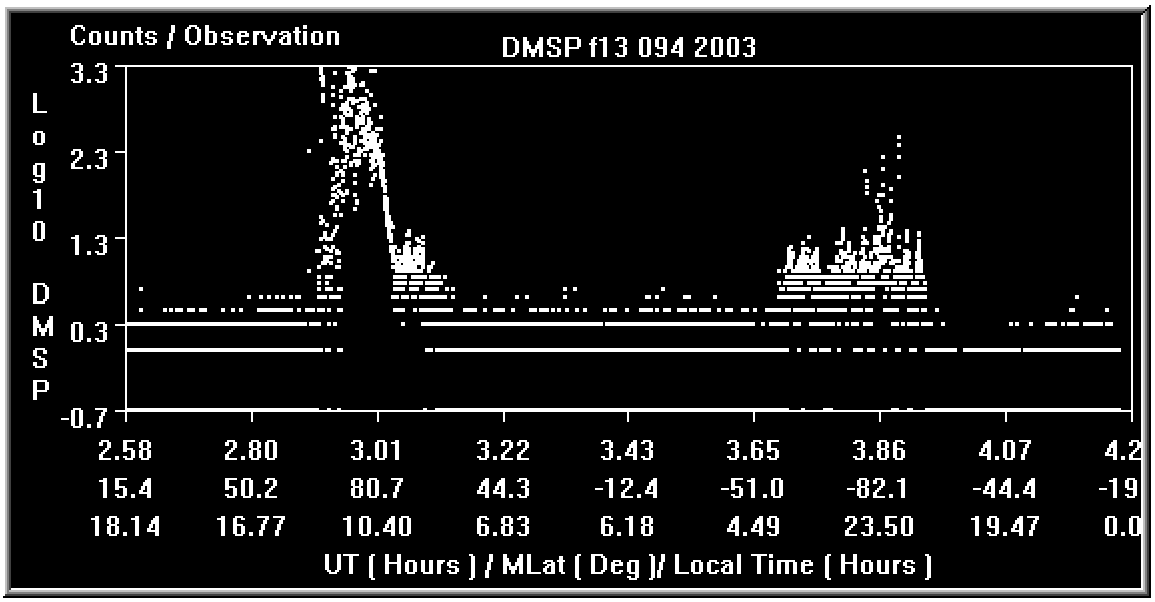
- To create the spectral viewport required, use the *Viewport* menu and select the *Spectral* under the *Projection* option. A white line frame will appear in the active window indicating that it has been converted to the spectral format. Now that a spectral viewport is active, the *Display* option also becomes active. Select *Display* and a pair of 2D energy spectrum plots will appear with ions and electrons represented in the upper and lower panels, respectively. The time range noted on the horizontal axis represents that of orbit 3 of DMSP-F13 on this day. Resize the graphics window so that the spectral window matches the following figure.



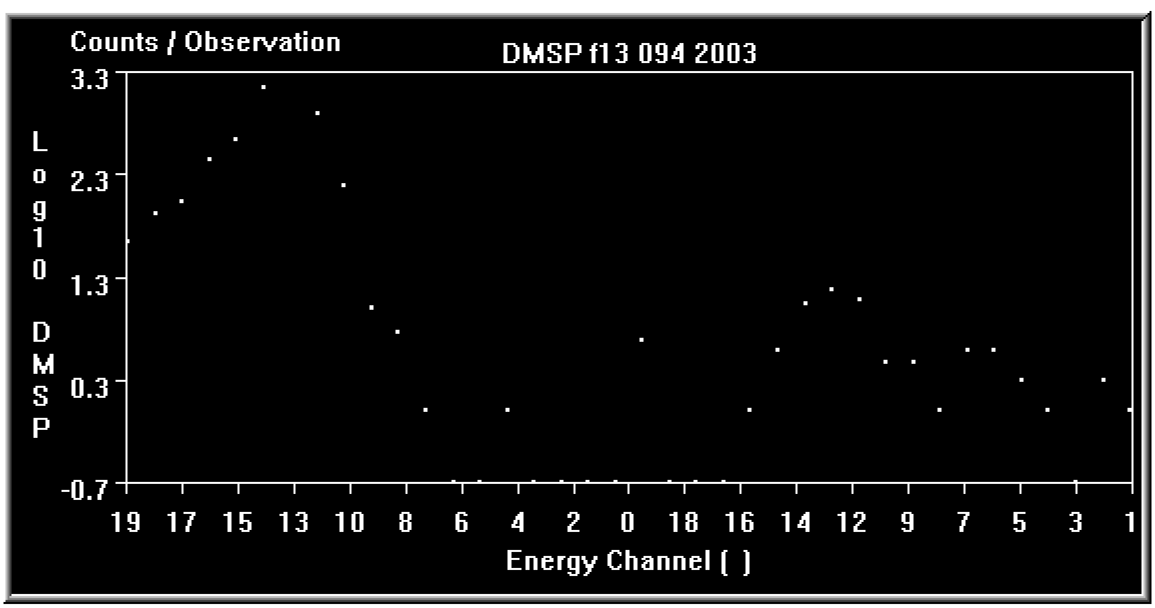
- (optional) To view data from another orbit, return to the *Module* menu and select the *Data* option again. *Available Modules* and *Active Modules* lists will appear. With the *AppDmsp* option highlighted in the *Active Modules* list, change the *Orbit Number (1-15)* setting from “3” to “4” and select *Run/Update* from the *Edit* pulldown menu to refresh the spectral viewport display. The display will now contain DMSP spectral data from orbit 4 of day 94 of 2003. To continue this exercise, reset *Orbit Number (1-15)* back to “3” and use the *Run/Update* option of the *Edit* menu to regain the display above. Now use the *Module* menu to reselect *Graphics* to return the display to the DMSP graphics window.

View 1-D Plots of DMSP Data Parameters as a Function of Energy Channel and Time

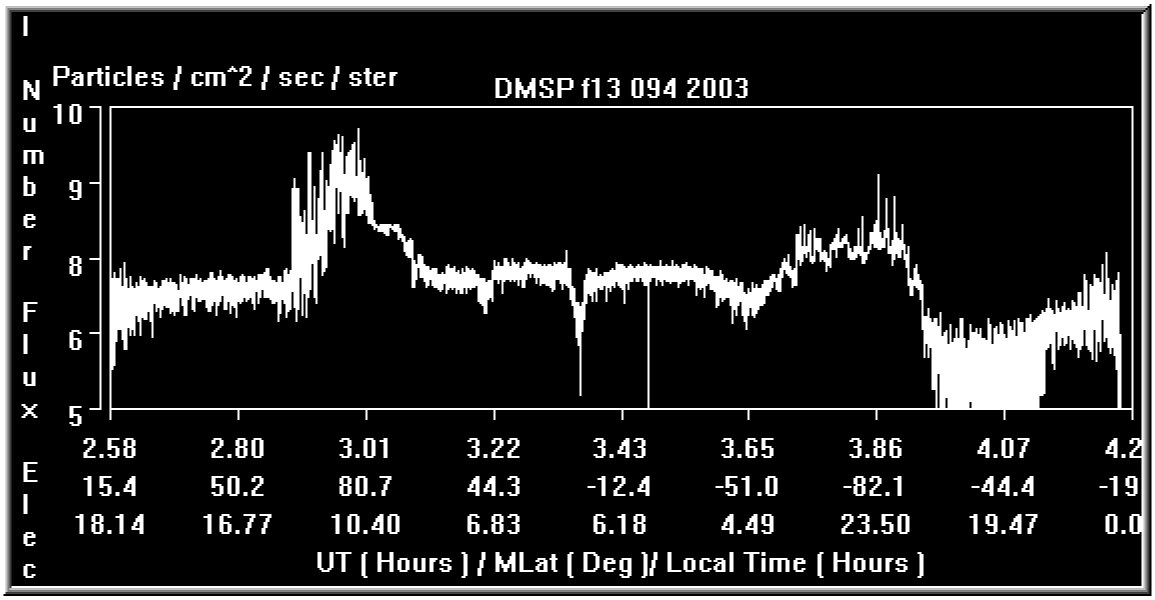
- To view 1D quantities available with the DMSP data set, use the *Window* menu and select *Create 1D Viewport* and a new 1D window will appear. Use the *Tile* option of the *Window* menu to get unobstructed views of the windows. Use the *1D Plot* selector and choose *Data Probe 0* and select *Display*. Move the *Position* slider to read 0.150 and the horizontal data probe line in the 2D window will be sampling an electron energy channel with relatively high fluxes. The counts measured along this probe line will now be displayed in the 1D window which should match the following figure.



- Select the *Y Axis* option above the *Position* slider and the data probe will sample all energy channels for a given time. With the *Position* slider set equal to 0.225, the 1D window should now match the following figure.



- To view one of the electron flux quantities integrated over all energy channels, use the *1D Plot* selector to choose the *INF-E* (integrated number flux for electrons). Change the *Type* from *Point* to *Line* and move the *Thickness* slider to the far left and the 1D window should resemble the following figure. Note the plot units are actually log(particles/cm^2/sec/ster).



Generate and View the DMSP-F13 Orbit in 3D

- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *SATEL-APP* (satellite application). An *AppSatel* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window

- With the *From File* element type option selected, click on the *File* button and a window will appears showing the contents of the folder $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled "orbits_for_ex14.txt" and click the *Open* button. A list of DMSP satellites will appear in the *Current Element File* list in the middle of the window.

- Highlight the *DMSP F13 04/02/03 23:24:24.00* entry of the *Current Element File* list as it contains the orbital elements appropriate for our start time. The satellite name and the reference time associated with the orbital elements are given in boxes below the list box. To view the orbital elements for this orbit satellite, click on the *Mean* element type button. Reselect the *From File* element type button to return to the previous view. The default value for the start time ("T-Start") is taken from the global values at the top of the Environment Window. Whenever a SATEL-APP module is run in "static" mode, a 1-day interval with a 60-second time step is used by default.

- Select the *Run/Update* option in the *Edit* menu to create the orbit data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

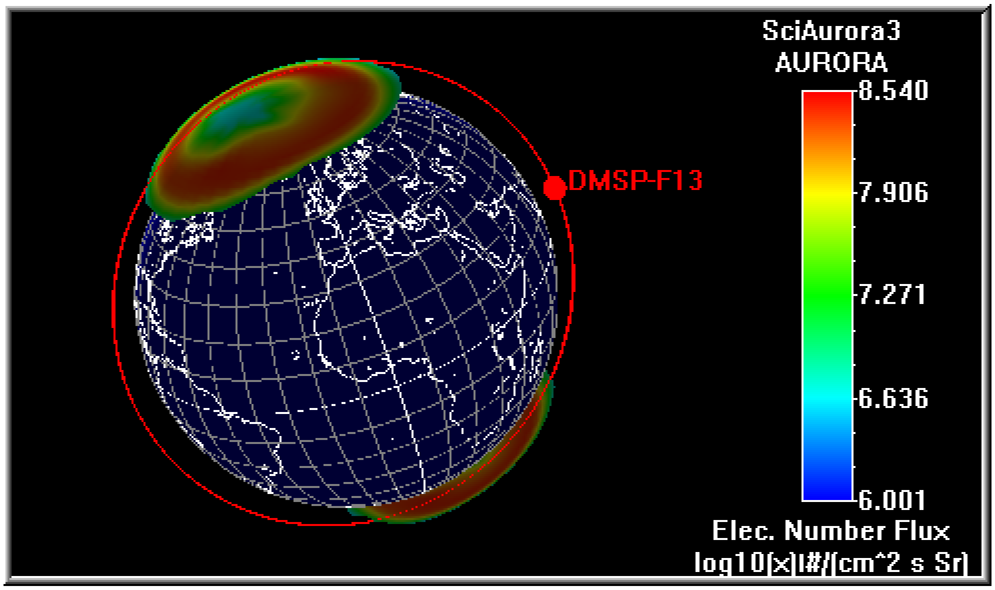
- Use the *Window* menu and select *Create 3D Viewport* and a new 3D window will appear. Select the *Graphics* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Earth*. An *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear in the Environment Window. Select the *Lat/Lon Grid* option and select *Display* and the Earth will appear in the active 3D window.

- Now scroll down the *Available Modules* list and highlight *Satellite*. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear in the Environment Window. Use the *Satellite* selector to choose DMSP-F13, change the *Reference Frame* selections from *Geocentric* to *Inertial (ECI)* and select *Display*, and the DMSP satellite orbit will appear in the active 3D window.

Generate and View a 3-D Auroral Science Model Data Set at DMSP Altitudes

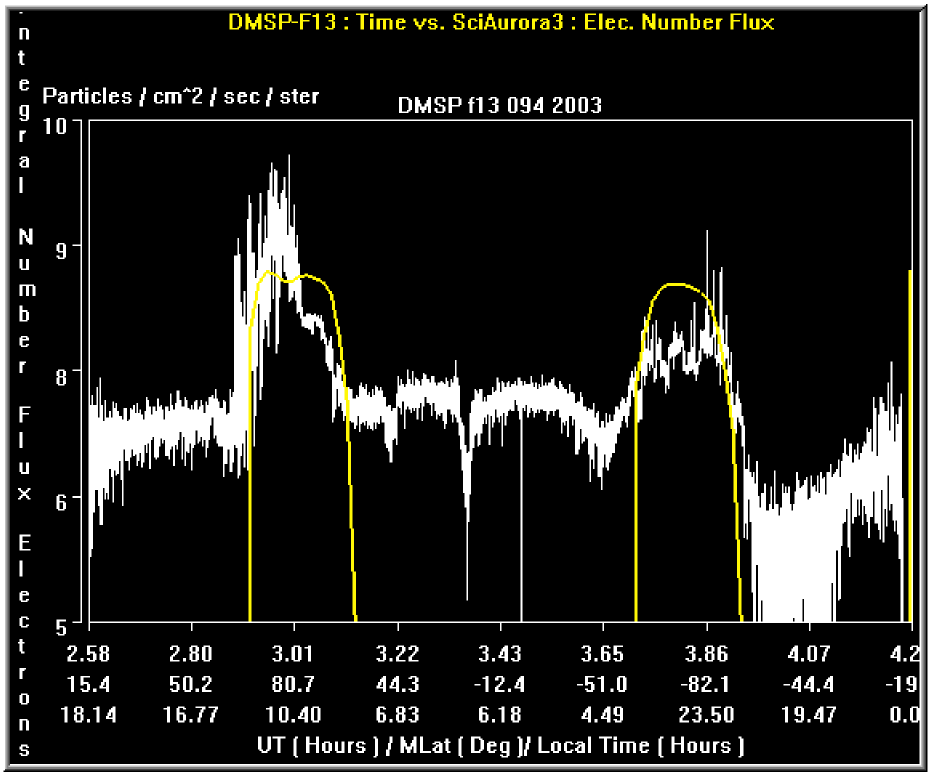
- Select the *Science* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Select *AURORA* from the *Available Modules* list. A *SciAurora* object will be added to the *Active Modules* list and a set of AURORA Options will appear in the Environment Window. To generate model output on a 3D grid that includes the DMSP orbit, select the *Grid Tool* option of the *Edit* menu and a *Grid Tool* window will appear. Within the Rad, GEOC (Re) section change *NPoint* from “1” to “3”, set *Max* = 1.3, and click *OK*. Select the *Run/Update* option in the *Edit* menu to create the 3-D auroral data set. When completed, the Model Status box will indicate that the “MODEL IS READY AND UP TO DATE.”

- Select *Graphics* from the *Modules* menu. *Available Modules* and *Active Modules* lists will appear. Select *Coord Slice* from the *Available Modules* list and a *Coord Slice* object will be added to the *Active Modules* list and a set of Coord Slice options will appear. Use the *Data* button to select *Elec. Number Flux* under the *SciAurora* option and click *Display*. The model electron number flux for the current Kp value will appear. Move the *Position Value* slider to approximately 0.410 to place the coordinate slide near the DMSP altitude. Use the left/right mouse buttons to rotate/resize the Earth to produce a picture resembling the following figure.



View the Auroral Model Output Along the DMSP Orbit Path

- Click on the existing1D Viewport to activate it. Scroll down the *Available Modules* list and select *Orbit Probe*. An *Orbit Probe* entry will appear in the *Active Modules* lists and a set of Orbit Probe options will appear in the environment window. Use the *Path/Abscissa* button to select *Time* under the *AppSatel* option. Use the *Data/Ordinate* button to select *Elec. Number Flux* under the *SciAurora* option. Select *Display* and the modeled electron number flux will appear in the 1D window. To make the Orbit Probe time axis match the DMSP orbit 3 time axis, adjust the entries in the *X Axis* section to read *Min* = 94.10764 and *Max* = 94.17846. Click in any other text box to update the plot. Uncheck the *Enabled* box in the X Axis section to remove the redundant horizontal axis scale (note that one was decimal days and the other in decimal hours). To add contrast, select the *Color* options and click the mouse in the yellow portion of the color wheel that appears. Move the *Thickness* slider slightly to the right. Finally, in the Y Axis section of the Orbit Probe options, set *Min* = 5.0 and *Max* = 10.0 and uncheck the *Enabled* box to remove the redundant vertical scale. With these adjustments, the 1D window should resemble the final figure.



In this last figure, we can see that the Hardy aurora model, driven solely by the Kp index, does a good job of specifying electron flux levels in the auroral bands. Remember that the flux is actually plotted on a log scale.

This completes the Example of DMSP Precipitating Particles: Data Versus Climatology.

15) Magnetospheric Specification Model (V2.5.1 Only, Dynamic)

The following example demonstrates the use of the Magnetospheric Specification Model (MSM) science module, the Satellite Application Module (SATEL-APP), and the Global Inputs, Coordinate Slice, Orbit Slice, and Orbit Probe graphical modules, and a variety of visualization tools.

Goal: View the 3-D evolution of plasma sheet electron and proton fluxes generated by the Magnetospheric Specification Model during a geomagnetically disturbed period and compare modeled particle fluxes along a geosynchronous and GPS orbit as a function of time.

Start an AF-GEOSpace session and set global input parameters

- Initiate AF-GEOSpace via the Start menu (Start > Programs > AFGeospace > AFGeospace), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- Establish a dynamic session by placing a check mark in the small box to the right of the *Start: UT* text field to activate the *End: Year, Day, UT* text fields. Edit the *Start* text fields so the *Year* = 1996, *Day* = 12, and *UT* = 18:00. Edit the *End* text fields so that *Year* = 1996, *Day* = 13, and *UT* = 18:00. Use the *Globals: Archive* option next to the time input fields to register the time period and automatically load parameters from the NGDC archive.

- View the global parameters for the interval selected using the *Globals* menu (between the *Viewport* and *Help* menus at the very top of the environment window) and selecting the *Show* option. Note that for all modules **except** the MSM, the global parameters can be modified by the user and saved for use during the current session. While the MSM actually accesses its own set of archived data to generate its inputs (see the MSM science module section), the values used for Kp, SumKp, SSN, Dst, and EqE (Equatorward Edge) will match those now visible in the *Globals* popup window. Dismiss the *Globals* window using the *Save* or *Cancel* buttons at the bottom.

Display plots of Kp, Dst, and the Equatorward Edge in a 1-D Window

- Select the *Create 1D Viewport* option from the *Window* menu to create a new 1-D graphics window to display the geomagnetic activity indices Kp and Dst.

- Select the *Graphics* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Global Inputs*. A *Global Inputs* object will be added to the *Active Modules* list and a set of Global Inputs options will appear in the Environment Window.

- From the *Value* input section, select the *Kp* option and check off *Display* to produce a plot of Kp versus time. Move the *Thickness* slider slightly to the right. To clean up this 1-D plot, reset the X Axis text field so that *Num Tics* = 5 to display 6 hour (0.25 day) intervals and

uncheck the *Grid* option in both the X Axis and Y Axis sections. Reset the Y Axis *Min* = 0.0, *Max* = 9.0, and *Num Tics* = 4. Click in any other text field to update the plot. Note that the Kp index ranges between 1.3 and 5.0 for this 30 hour interval.

- Select *Global Inputs* again from the *Available Modules* list. A second *Global Inputs* object will be added to the *Active Modules* list and a new set of Global Inputs options will appear in the Environment Window.

- From the *Value* input section, select the *DST* option and select *Display* to plot Dst in the existing 1-D window. Move the *Thickness* slider slightly to the right. Uncheck the *Enable* box for the X Axis to remove the redundant time labels, select the *Right* option for the Y Axis, and uncheck the *Grid* option in both the X Axis and Y Axis sections. Reset the Y Axis *Min* = -100.0, *Max* = +20.0, and *Num Tics* = 7. Click in any other text field to update the plot. Note that the Dst index ranges between -88 nT and +8 nT for this same interval.

- Select *Global Inputs* again from the *Available Modules* list. A third *Global Inputs* object will be added to the *Active Modules* list and a new set of Global Inputs options will appear in the Environment Window.

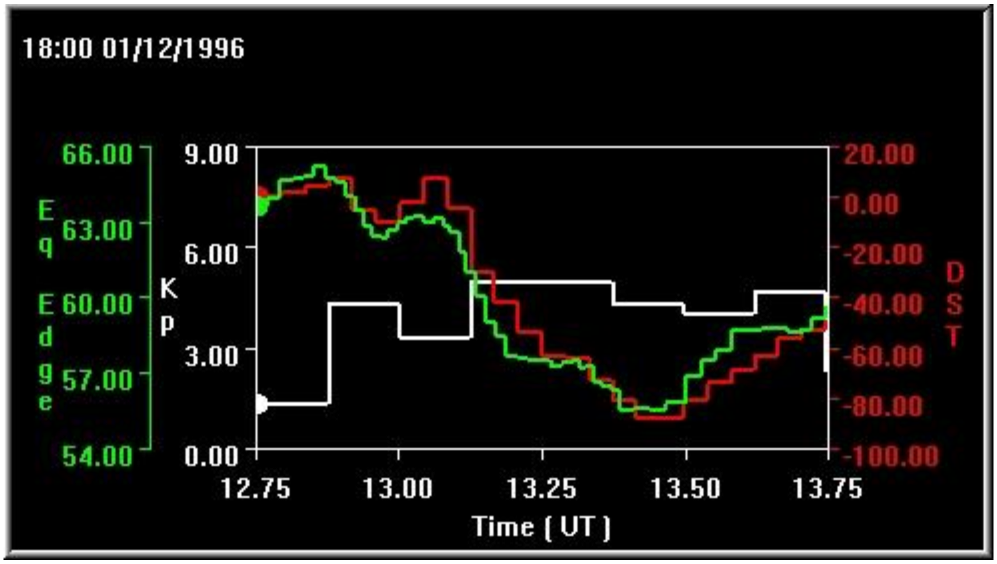
- From the *Value* input section, select the *EqEdge* option and select *Display* to plot Eq Edge in the existing 1-D window. Move the *Thickness* slider slightly to the right. Uncheck the *Enable* box for the X Axis to remove the redundant time labels and uncheck the *Grid* option in the Y Axis sections. Reset the Y Axis *Min* = 54.0 and *Max* = 66.0. Click in any other text field to update the plot. Note that the equatorward edge of the diffuse aurora at midnight (Eq Edge), measured in degrees latitude, is an indicator of magnetic field line stretching in the magnetotail. Typically, the nightside magnetic field becomes more stretched (i.e., Eq Edge decreases) as the inner magnetospheric magnetic field becomes more inflated (i.e., as Dst decreases) and thus Dst and Eq Edge profiles often resemble each other. The Eq Edge also has an inverse relationship with Kp which is not very evident in this example.

- Scroll up the *Available Modules* list and select *Annotation*. An *Annotation* object will be added to the *Active Modules* list and a set of Annotation Options will appear in the Environment Window. Check the *Show Date* and the *Display* boxes and use the *X* and *Y Position* sliders to move the annotation to the top. The 1D window should resemble the next figure.

Run an MSM Simulation and Create Electron and Proton Data Sets,

- Select the *Science* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *MSM* (Magnetospheric Specification Model). An *MSM* object will be added to the *Active Modules* list and a set of MSM Options will appear in the Environment Window

- While not a model input, a descriptive phrase (maximum of 68 characters) can be placed in the *Run ID* text box to label the simulation run. It can serve as a useful reminder of the global time interval settings, for example, when the science module is saved to be



accessed in the future. Edit the *Run ID* text box to read "MSM – Example 15, 1996 Day 12 18:00 – Day 13 18:00".

- For the *Kp Mode*, select the *Full MSM (Kp to fill gaps)* option and an *MSM: Use Input* popup window will appear. Place check marks next to *DST*, *EQ. Edge*, and *PCP* and leave the default *No IMF, XIPATT* selection. Click the *OK* button and the Dst index, the equatorward edge boundary of the diffuse aurora, and the polar cap potential drop will be used as direct inputs to the model. All other required model inputs will either be default values or be derived automatically using Kp-proxy relationships internal to the MSM science code. In this case, the default symmetric ionospheric electric potential pattern (otherwise determined using either the *IMFBY, IMFBZ* or *XIPATT* inputs) will be assumed and the magnetopause stand-off distance (calculated internally by the model using *SWDEN* and *SWVEL*) will be calculated from Kp.

- Leave the *Run Prefix* text box reading "x" (used as a file name prefix internally by the MSM) and place a check mark next to the *H+* option below (e- should already be checked) so that both electrons and protons will be tracked by the simulation. The *Energy Range (keV)* and *L-Shell Range* options can remain unchanged as the default settings will result in the maximum energy range of particles to be followed. Leave the *Run Mode* set as *Base/Map* so that the base MSM simulation and the mapping procedure will be executed in sequence. The *Check Modes* button will bring up a window with short notes applicable to the MSM run associated with the entered *Run Prefix*, e.g., it will indicate if a run with that prefix already exists

- The particle species/energy pairs to be mapped onto the 3-D grid (to be defined in the next step using the *Grid Tool* option of the *Edit* menu) are selected using the *Set Map Energies* button. Click this button and an *MSM Energies* window appears with active columns for electron and proton energies (because e- and H+ were selected in the main MSM environment window). Leave the default 30 keV entry for the "0" entry in the *e-Energy (keV)* column and edit the "0" entry in the *H+ Energy (keV)* column to also read

30 keV. Click the *Update* and *Done* buttons to register the selection and close the window.

- Select the *Grid Tool* option of the *Edit* menu and note that the default settings extend the grid out to beyond 14 Re which is the largest magnetopause stand-off distance used by the geomagnetic field model employed by the MSM. The mapping procedure will attempt to extract particle fluxes from the simulation at the energies selected in the previous step for each grid point. Leave the default setting and close the *Grid Tool* window using the *OK* button. In the future, if the user is interested in limiting the volume processed then the grid can be adjusted. For example, if geosynchronous orbit is the only region of interest, then the Grid Tool System could be changed to GEOC and the Latitude range could be limited to values closer to the equator. Note that the mapping procedure speed increases as the grid volume gets smaller.

- One additional step is required in order to plot magnetic field quantities and the species/energy pairs selected two steps above. Select the *Dynamic Tool* option of the *Edit* menu to get the *Dynamic Tool* popup window to appear. Because we filled in the "0" entries for both the *e-* and *H+ Energy (keV)* columns of the MSM Energies window earlier, we must also check the corresponding write-to-file quantities, i.e., leave the check next to *eEnergy0* and place a check next to the *hEnergy0* options. Check the *Bx, By, Bz,* and *Btot* options also if you like to view magnetic field values generated by the MSM magnetic field model [*Hilmer and Voigt*, 1995]. Note that with the 900 second (15-minute) native time-step of the MSM, 97 simulation steps will be calculated to cover the 24 hour period. To reduce running time, set the *Time Step (sec)* = 1800 to map the output only once every 30 minutes. Click the *Update List* button to fix the selections and the *Done* button to close the window.

- Select the *Run/Update* option in the *Edit* menu to create the particle flux and magnetic field data set. Note that this run will take several minutes. While the *Process View* window does not indicate progress until the mapping procedure begins, the actually running of the MSM simulation can be followed by looking at one of the DOS execution windows. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

- As mentioned above, the inputs selected to drive this run (default *Kp* plus optional parameters *DST*, *EQ. Edge*, and *PCP*) are used by the MSM to produce the complete set of parameters needed at the 15-minute simulation mark times. To view these parameters click on the *Show MSM Inputs* button at the bottom of the MSM environment window. The values for Dst, EqE, and PCP are all determined via interpolation and the magnetopause standoff distance (Std) is derived via a Kp relationship. If parameters *IMFBY, IMFBZ* or *SWDEN, SWVEL* had been selected above, then their interpolated values would also be listed and the Std value would have been derived using SWVel and SWDen values. The column labeled "P" refers to the polar cap potential pattern type used and in this case the value of 2 indicates a dawn-dusk symmetric electric field pattern. If the user is interested in seeing the raw inputs used to create the *Show Inputs* table, they can examined some of the files in the SciMSM#

folder created in the user's scratch space (see details in the *Show Inputs* portion of the MSM Science Module section).

Display the Earth, SM Axes, and Sun Vector in the GSM Coordinate Reference Frame,

- Click on the original blank 3-D graphics window to activate it. Select the *Graphics* option in the *Modules* menu and *Available Modules* and *Active Modules* lists will appear. Select *Earth* from the *Available Modules* list. An Earth object will be added to the *Active Modules* list and a set of Earth Options will appear in the bottom of the Environment Window. Select the Grid Option *Lat/Lon Grid* to add the geographic markings. Click in the *Display* box to place the Earth in the 3D Window. The left and right mouse buttons can be used to rotate and scale the Earth image while the cursor is in the Window.

- Highlight the *Annotation* entry in the *Active Modules* list on the right side of the environment window and check *Display* to place the existing time/date annotation in the 3-D window.

- Select *Axes* from the *Available Modules* list and an Axes object will be added to the *Active Modules* list. Change the Axes Frame selection from the default *GEOC* to *SM* and also select the *Sun Vector* option. The Solar Magnetic (SM) coordinate system is useful because the Earth's magnetic dipole is aligned with the SM z-axis (see the Grid Tool section of the documentation for coordinate system definitions). Click the *Display* box and a set of orthogonal axes in the SM coordinate system (red, green, blue) will appear. Notice that the North magnetic pole (blue axis) is located about 11 degrees from the geographic North Pole near Greenland. The yellow axis is the sun vector.

- From the *Viewport* menu, select *View Position* and then the *GSM* option. This will keep the 3-D graphics window fixed in the GSM frame during animation (matching the MSM simulation Grid Tool coordinate frame), i.e., the Earth will rotate and the sun vector (defined to be coincident with the GSM x-axis) will remain fixed. From the *Viewport* menu, remove the check mark from the *Perspective* setting. Use the left mouse button to orient the Earth such that the sun vector (yellow) points to the left and the SM y-axis (green) points directly out of the screen.

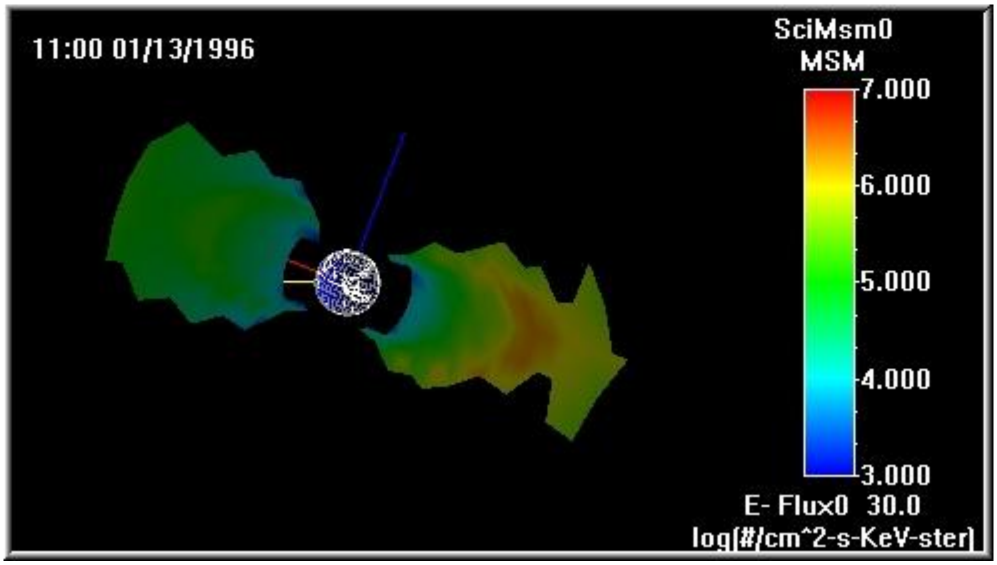
- Select the *Animate Tool* from the *Edit* menu and the *Animate* window will appear. Reset the *Time Step (Sec)* field to 1800 and click the *Update* button. Use the left-right slider arrows to change the time by 1800 second steps and note how the Earth's magnetic dipole (coincident with the SM z-axis; blue) wobbles in this GSM coordinate frame. During this early time of year, the northern dipole is always tilted away from the Sun. In the 1-D window, the changing time can be seen as the annotation changes and marks move along the Kp, Dst, and Eq Edge parameter lines. Return the *Animate* window slider to the far left and close the window with the *Done* button.

View an Animation of Electron Fluxes in the GSM Noon-Midnight Plane

- To display the electron particle flux values stored on our GSM grid, select *Coord Slice* from the *Available Modules* list. A Coord Slice object appears in the *Active Modules* list and a set of Coordslice Options appear in the Environment Window. Click on the *Data* button, and

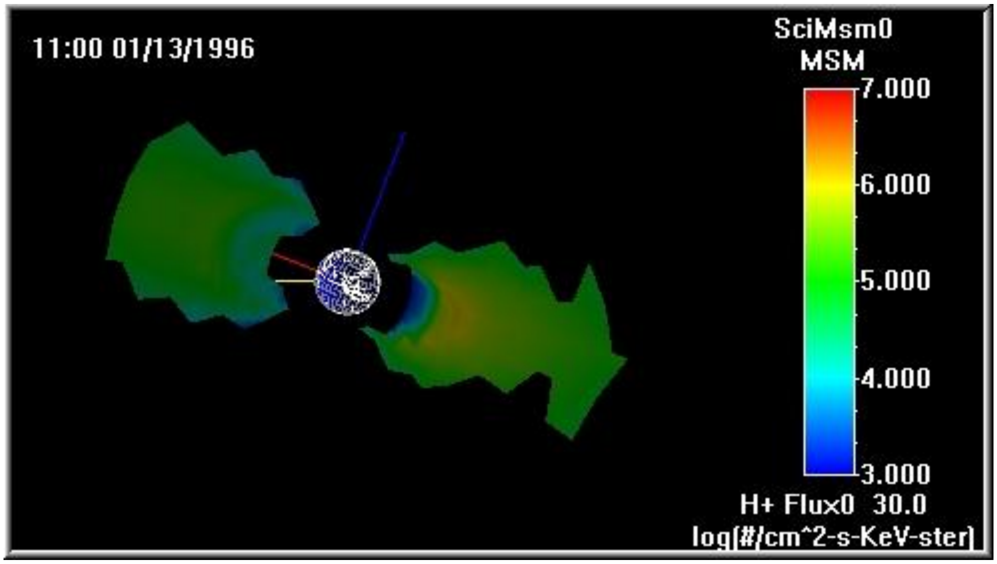
under the *SciMsm0* option, choose *E- Flux0 30.0*, and click *Display*. To get a coordinate slice aligned with the GSM X-Z plane select Cut Plane *C2*. Remember that the right mouse button can be used to resize the display contents. Select the *Data Map* option and reset *Data Min* = 3.00 and *Data Max* = 7.00 at the bottom of the environment window.

- To view a similar coordinate slice on the sunward side of the Earth, repeat the last step to create another coordinate slice and then move the Position Value slider to 0.500. The 3-D graphic window should resemble the following figure.



- Open the *Animate Tool* in the *Edit* menu and view the MSM sequence using the *Animate* switch and the slider arrow in the *Animate* Window. Note that some of the peak fluxes occur near and the Dst minimum during this event. The 30 keV electrons remain trapped on magnetic field lines which are fairly dipolar near the Earth, thus the electron distributions stay approximately aligned with the SM axis plotted. The peak fluxes near the SM equatorial plane designate the center of the magnetospheric plasma sheet. The motion of this plasma sheet is discussed in relation to magnetic field topology in Example 3 in this document. The distribution of 30 keV protons is similar but fluxes are lower and not as broadly distributed. The next (optional) step will produce a similar picture of proton fluxes.

- (Optional step) To obtain the same view of the proton flux values stored on our GSM grid, highlight each *Coord Slice* entry in the *Active Modules* list, click on the *Data* button, and under the *SciMsm0* option, choose *H+ Flux0 30.0.* For each *Coord Slice* entry you must again select the *Data Map* option and reset *Data Min* = 3.00 and *Data Max* = 7.00 at the bottom of the environment window. If the *Data Map* option is already selected (and its options are not visible), then select any other option and reselect *Data Map* to view them. The 3-D graphic window would now resemble the following figure.



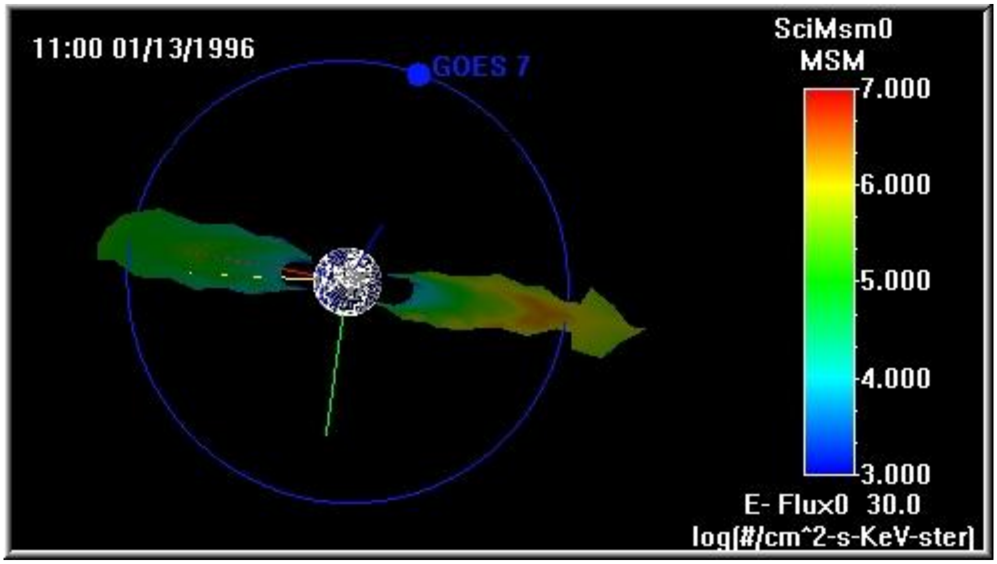
Create and Display a GEO Orbit

- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *SATEL-APP*. An *AppSatel* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window

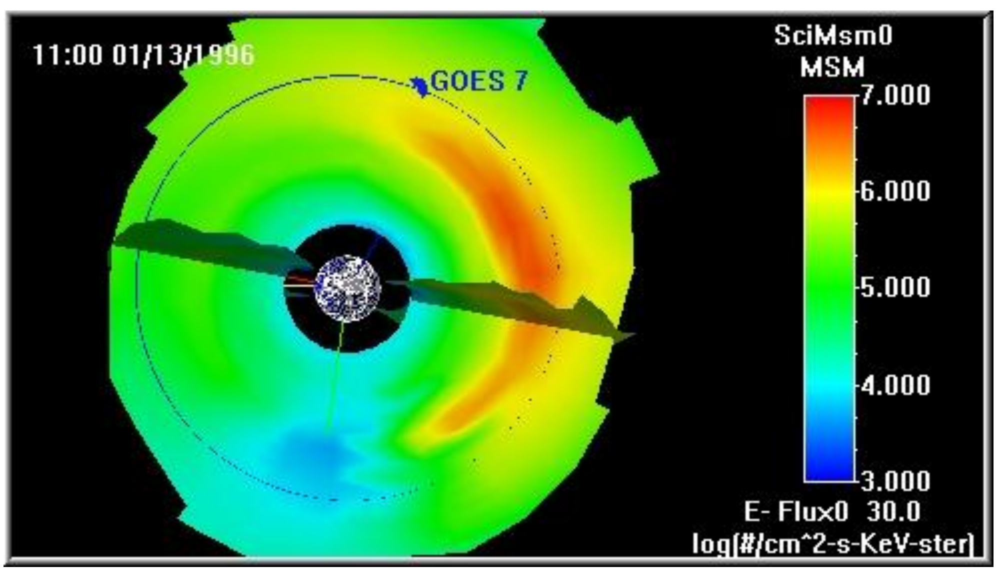
- With the *From File* element type option selected, click on the *File* button and a window will appears showing the contents of the folder $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled “goes.txt” and click the *Open* button. A list of GOES satellites will appear in the *Current Element File* list in the middle of the window. Highlight the *GOES 7* entry and then use the *Run/Update* option in the *Edit* menu to create the orbit data set. When completed, the Model Status box will indicate that the “MODEL IS READY AND UP TO DATE.”

View Electron Fluxes in the GEO Orbit Plane

- Select the *Graphics* option in the *Module* menu and *Available Modules* and *Active Modules* lists will reappear. Scroll down the *Available Modules* list, select *Satellite*, and *Satellite Options* will appear. Pick the *GOES 7* entry of the *Satellite* selector, check *Display*, and the GOES 7 satellite will appear in the 3-D window. Under *Reference Frame*, uncheck *Geocentric* and then check *Inertial (ECI)* so that a trace of the entire orbit path is visible. Use the *Color* option to change the orbit to the color blue by clicking directly on the blue area of the color wheel that appears With the left mouse button depressed, move the mouse down to bring the north geographic pole and the entire geosynchronous orbit path in view so that the 3-D window now resembles the following figure. Note that highlighting one of the active *Coord Slice* entries will refresh the color bar labels.



- To view the electron flux in the geosynchronous orbit plane, scroll up the *Available Modules* list, select the *Orbit Slice* option and a set of Orbit Slice options appear. Select GOES 7 from the *Satellite* list. Click on the *Data* button and choose *E- Flux0 30.0* under the SciMsm0 option, select the *Orbit Plane* option *P3*, and click *Display*. Use the *Data Map* option to set *Data Min* = 3.00 and *Data Max* = 7.00 to match the existing coordinate slices displayed. Use the *Animate Tool* from the *Edit* menu to toggle the time step away and back to the 11:00 mark so that the Orbit Plane fluxes are properly set. The 3-D window should now resemble the following figure.



- Use the *Animate Tool* of the *Edit* menu to survey the development of the 30 keV electron flux in the geosynchronous orbit plane. (Note that because we fixed the view in the GSM coordinate frame earlier, the geosynchronous orbit will appear to wobble slightly. Use the *View Position* option of the *Viewport* menu and select the *GEI* option to fix geographic based orbit in the window during animation while keeping the sun vector pointing to the left.) Note

that the initial MSM particle fluxes are symmetric about the Earth and that it takes several hours for realistic distributions to become established. After the artificial effects of the initial condition disappear, it is evident that the modeled source for electrons is on the night side of magnetosphere and that the electrons drift earthward from the magnetotail and then move eastward to wrap around to the dayside. The size of the simulation region changes as the magnetopause standoff distance changes (in this case following Kp) to decrease in size during the middle period then increase again toward the end of the interval. With the *Orbit Slice* entry highlighted in the *Active Modules* list and change the *Data* selection to *H+ Flux0 30.0* and view an animation of the protons. Use the Data Map option to ser the Data Min = 3.0 and the Data Max = 7.0. Although not apparent in this view, the proton distribution is also initially symmetric like the electrons, but protons drift westward when they reach the inner magnetosphere from the tail. (To properly view the symmetric initial condition, one should really view a *CoordSlice* using Cut Plane *C1* with *Position Value* = 0.5.)

Create and Display a GPS Orbit

- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *SATEL-APP*. An *APPSatel* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window

- Select the *From File* element type option and click on the *File* button and a window will appears showing the contents of the folder $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled "gps.txt" and click the *Open* button. A list of GPS satellites will appear in the *Current Element File* list in the middle of the window. Select *GPS BII-08.* Select the *Run/Update* option in the *Edit* menu to create the orbit data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

- Select the *Graphics* option in the *Module* menu and the *Available Modules* and *Active Modules* lists will reappear. Scroll down the Available Modules, select *Satellite*, and *Satellite Options* will appear. Pick the GPS BII-08 entry of the *Satellite* selector, and then check *Display* and the GPS satellite will appear in the 3-D window. Under *Reference Frame*, uncheck *Geocentric* and then check *Inertial (ECI)* so that a trace of the entire orbit path is visible.

Compare Electron Fluxes Along a GEO and GPS Orbit

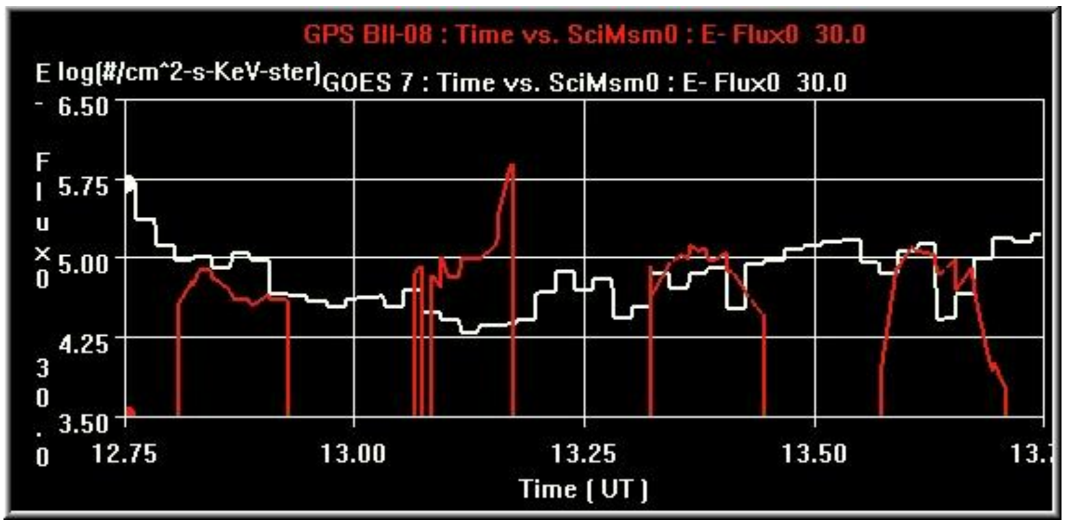
- Select the *Create 1D Viewport* option from the *Window* menu to create a new 1-D graphics window. Remember that the Window menu options *Tile* and *Cascade* can be used to manage window viewing.

- Scroll up the *Available Modules* list and select *Orbit Probe*. An *Orbit Probe* object will be added to the *Active Modules* list and a set of Orbit Probe options will appear in the Environment Window.

- Select the *Time* option of the first *AppSatel* entry using the *Path/Abscissa* button. Now select the *E- Flux0 30.0* option of the *SciMsm* entry using the *Data/Ordinate* button and click

Display and a plot of GOES 7 electron flux vs. time will appear in the new 1-D window. Reset the *Y Axis* values *Min* = 3.5 and *Y Axis Max* = 6.5. Move the *Thickness* slider to the right slightly to thicken the line. Click in any other text box to update labels. If necessary, use the *Color* option and click in the center of the color wheel that appears to change the flux trace white.

- To generate a similar plot for the GPS satellite, repeat the procedure in the previous two bullets except this time select the *Time* option of the **second** *AppSatel* entry using the *Path/Abscissa* button. After resetting the *Y Axis Min* = 3.5 and *Max* =6.5 so that the Y Axis labels match those of the GOES plot, remove the redundant axes labels by removing the check mark in the two *Enable* boxes in both the X Axis and Y Axis sections. Use the *Color* option to change the trace to red and increase the line thickness slightly. The new 1-D window should resemble the following figure.



- Use the *Animate Tool* of the *Edit* menu to survey the time history of the 30 keV electron flux in the GOES and GPS satellites. As indicated in the 1-D window, the 3-D window also shows that the GPS satellite at 4.2 Re traverses the plasma sheet twice an orbit and actually samples higher fluxes than the GOES satellite which remains within the plasma sheet the entire simulation at 6.62 Re.

This completes the Example of the Magnetospheric Specification Model.

16) Ionospheric Plasma Bubbles: Flux Tube Specification

The following example demonstrates the use of the BFOOTPRINT Application Module, the BFIELD Application Module, and a variety of visualization tools.

Goal: Ionospheric plasma bubbles are depletions in ionospheric electron density which are detectable by instruments on the DMSP and ROCSAT satellites. If satellites on different orbits detect depletions in a particular region at nearly the same time, it is possible that they may be sampling parts of a larger plasma bubble structure. The goal of this example is to estimate the spatial extent of an ionospheric plasma bubble measured by multiple spacecraft by mapping geomagnetic field lines from locations within the bubble. The volume defined by this collection of field lines will be used to estimate the full extent of the plasma depletion.

Start an AF-GEOSpace session and set global input parameters

- Initiate AF-GEOSpace via the Start menu (Start > Programs > AFGeospace > AFGeospace), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this static run, set the Global Parameters as follows: *Start:Year*=2000, *Day*=62, *UT*=13:15. Click on the *Globals: Archive* option to the right of the time input fields to load the archived NGDC parameter values (*Kp*=2, *SSN*=130, *F10.7*=209.6, and *Ap*=7).

Create the DMSP and ROCSAT orbit data sets

- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear.

- Select *BFOOTPRINT-APP* from the *Available Modules* list. An *APPBFootprint* object will be added to the *Active Modules* list and a set of B-Field Footprint Application options will appear in the Environment Window

- For each satellite that encountered a plasma bubble, we will trace field lines from three locations along the portion of the orbit path intersecting the bubble, i.e., from the plasma bubble entry and exit points and from one point between the two. To accomplish this, make the following changes:

  - While the *Setup: Footprint Model* option is selected, set the *Foot Line Inputs* to be *From Satellite,* change the *Satellite Orbit Steps* to “3”, and select the *Internal B-field* option *IGRF(1945-2010)*.

  - Select the *Setup: Satellite* option and Ephemeris Data options will appear. Leave the *From File* option selected and click the *File* button and a window will appear showing the contents of the folder $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled

"orbits_for_ex16.txt" and click the *Open* button. A list of three satellites will appear in the *Current Element File* list in the middle of the window.

- Select the *DMSP-F12* entry and the satellite name and the reference time associated with the orbital elements will appear in boxes below the list box. DMSP-F12 measured a plasma depletion for 4 minutes. To generate the orbit for this interval, edit the text boxes such that *T_start* = "03/02/00 12:50:00.0", *T_stop* = "03/02/00 12:54:00.0", and *Time Step(s)* = "10". Select the *Run/Update* option in the *Edit* menu to create the orbit data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

- Process the next two satellites of the *Current Element File* list in the same manner by repeating the instructions in the last three bullets twice but changing the choices used in the last bullet each time. This will result in three *AppBFootprint* items in the *Active Modules* list.

  - For DMSP-F15, which passed thru a plasma depletion for six minutes, edit the text boxes such that *T_start* = "03/02/00 13:28:30.0", *T_stop* = "03/02/00 13:34:30.0", and *Time Step(s)* = "10".

  - For ROCSAT, which passed thru a plasma depletion for more than a minute, edit the text boxes such that *T_start* = "03/02/00 13:14:25.0", *T_stop* = "03/02/00 13:15:35.0", and *Time Step(s)* = "10".

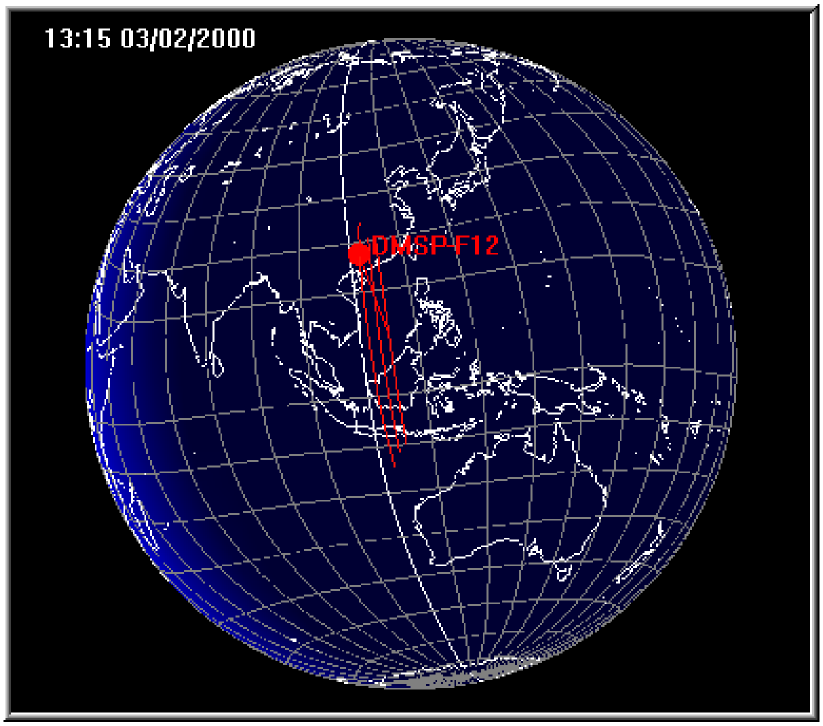
Display the Earth and Time/Date Annotation

- Select the *Graphics* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Earth*. An *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear in the Environment Window. Select *CGM Grid* from the Grid Options section and select *Display* and an Earth with corrected geomagnetic coordinate grid will appear. Use the Viewport pulldown menu to deactivate (uncheck) the *Show Color Bar* and *Perspective* options.

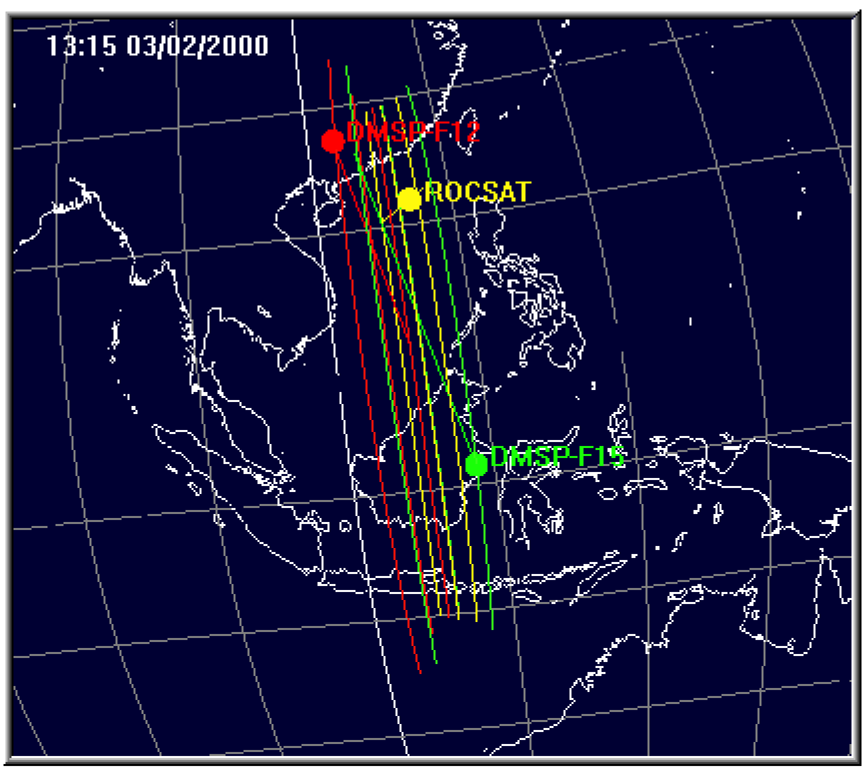
- Scroll up the *Available Modules* list and select *Annotation*. An *Annotation* object will be added to the *Active Modules* list. Select the *Show Date* option and click *Display*. Adjust the *X* and *Y Position* sliders so that the annotation appears in the upper left of the window.

Display the DMSP and ROCSAT Orbit Paths with Traced Field Lines

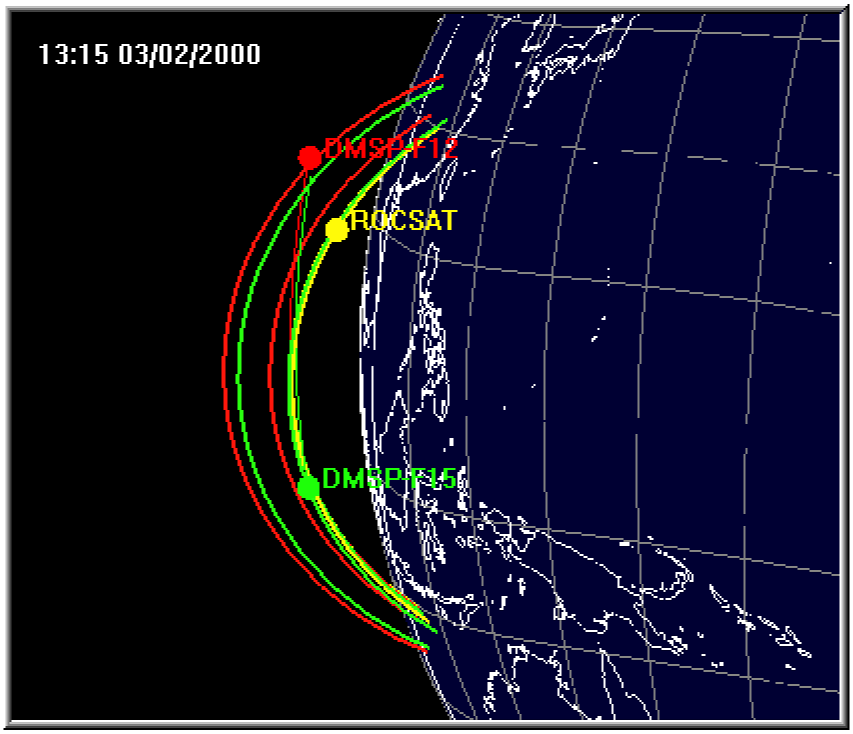
- Scroll down the *Available Modules* list and select *Satellite*. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear in the Environment Window. Select the *Satellite* called *DMSP-F12*, select the *Pop Label* option, and click *Display* and a short section of that orbit will appear over Southeast Asia. Use the left mouse button to reposition the Earth to bring the orbit within view. Now scroll up the *Available Modules* list and select *Field Lines* and a *FieldLines* object will be added to the *Active Modules* list. Use the *Data* button to select the *Footprint Lines* options under the first *AppBFootprint* listed and click *Display*. Increase the *Line Width* to "2" and use the *Color* option to change the field line color to match that of the orbit, i.e., red. Now zoom in using the right mouse button to get the following figure.



- Repeat the previous step once for DMSP-F15 and once for ROCSAT using their corresponding field lines represented by the 2nd and 3rd *AppBFootprint* choices in the Field Lines Options *Data* list, respectively. As each new item is displayed, use the *Color* option to color all DMSP-F15 related items green and all ROCSAT related items yellow. Use the right mouse button to zoom in and the window should resemble the following figure.



- Because electrons move much more freely along magnetic field lines, this collection of field lines helps define a larger volume, i.e., a magnetic flux tube, where the plasma depletion was observed. Use the left/right mouse buttons to rotate/zoom the picture so you can see the collection of field lines from the side as in the next figure. Note that the DMSP and ROCSAT satellite traverse this region at different altitudes and that the magnetic field lines straddle the magnetic equator and their footprints cluster near ±20º CGM.

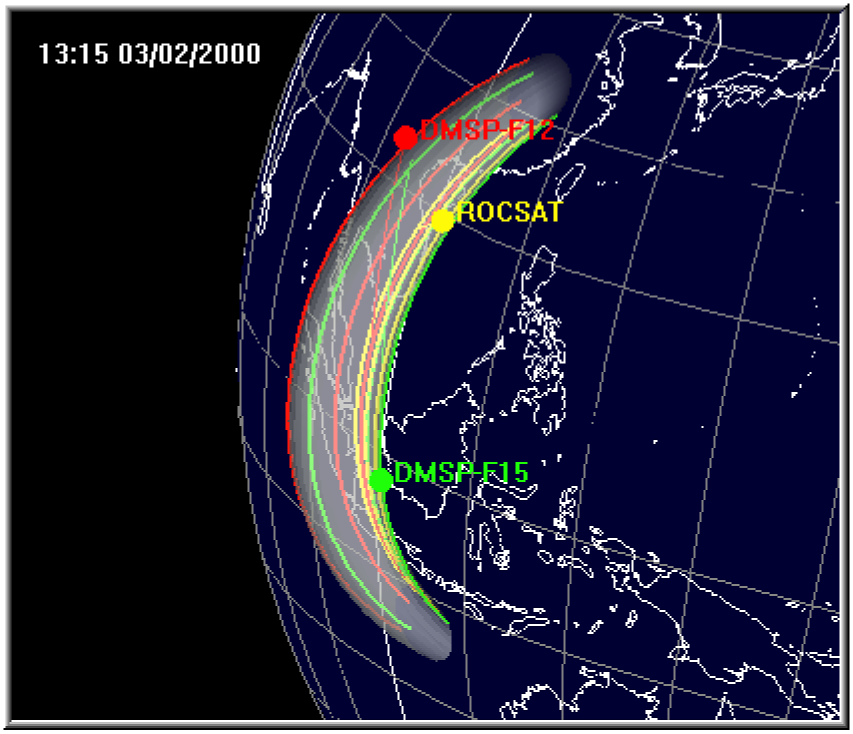


Create and Display a Single Flux Tube Enclosing the Traced Magnetic Field Lines

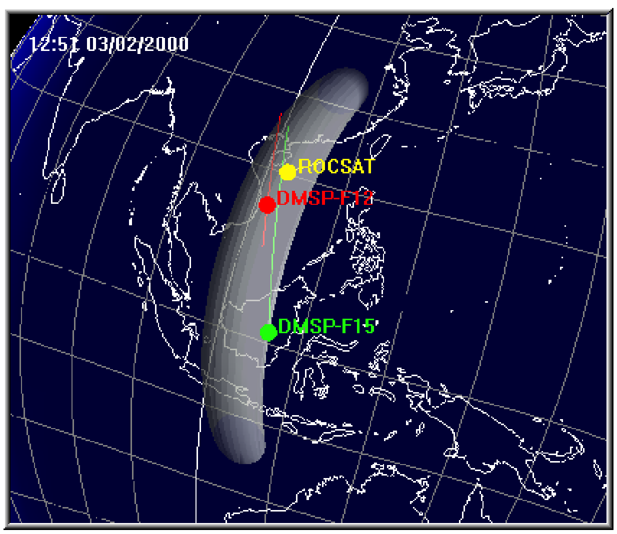
- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Select *BFIELD-APP* from the *Available Modules* list and an *APPBField* object will be added to the *Active Modules* list and a set of B-Field Application Parameter options will appear in the Environment Window. Adjust the selections in the *Generate* section such that *Flux Tube* is the only selected item. Select *IGRF (1945-2010)* in the *Internal B-Field* section and leave the *External B-Field* set to *None*. In the *Flux Tube Inputs* section leave the *Geographic* option selected and edit the other text boxes such that *Lat* = 28.9, *Long* = 113.9, *Alt(km)* = 0.0, *Diam(km)* = 650, and *Steps* = 30. Select the *Run/Update* option in the *Edit* menu to create the flux tube data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

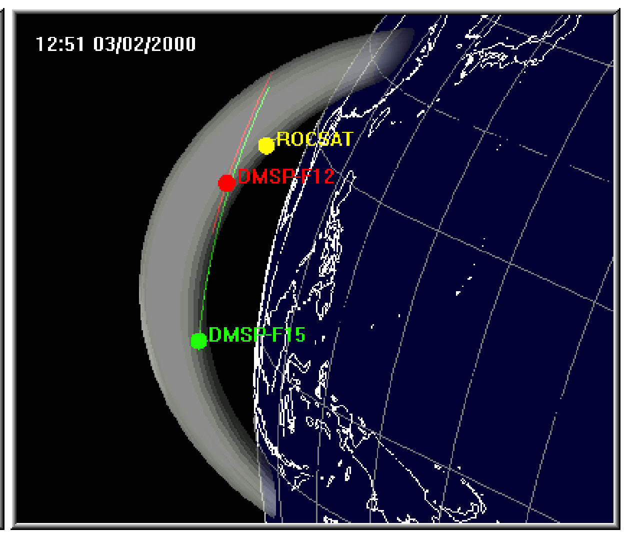
- Select the *Graphics* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Field Lines*. A *FieldLines* object will be added to the *Active Modules* list and a set of Field Line Options will appear in the Environment Window. Use the *Data* button to select *Flux Tube* under the *AppBField* option and click *Display*. Change the *Plot Type* from *Field Lines* to *Filled Surface* and then

use the *Color* option to change the tube color to white. Finally, use the *Transparency* option and move the transparency slider to 0.50. The figure should now resemble the following.



- To get a view of just the satellite orbits and the flux tube they are traversing, select each of the first three *FieldLines* entries in the *Active Modules* lists and remove the check from *Display*. Open the *Animate Tool* using the *Edit* menu and the *Animate* window will appear. Edit the text fields such that *Time Start* = "03/02/00 12:50", *Time End* = "03/02/00 13:35", and *Time Step (Sec)* = "60" and click the *Update* button.





- View the sequence of satellites as they traverse the model of the plasma depletion flux tube by clicking on the right-hand slider arrow in the *Animate* window. You will see DMSP-F12

move northward during the first few minutes, ROCSAT move eastward starting at time 13:14, and DMSP-F15 move northward starting at 13:28. With the *Animate* window slider set at 12:51, the display should resemble the figure on the left above. Now rotate/translate the Earth to create the alternate view above. It is easier to see with these displays that while the DMSP spacecraft may have sampled the plasma depletion over a relatively wide set of latitudes, the ROCSAT satellite seems to have just caught the lower edge of the flux tube structure.

This completes the Example of Ionospheric Plasma Bubbles: Flux Tube Specification.

17) Radar Auroral Clutter

The following example demonstrates the use of the Satellite Application Module (SATEL-APP), the AURORA Science Module, the EMITTER Graphics Module (to create a 3D radar fan), and a variety of visualization tools.

Goal: Backscatter reflections from electron density irregularities aligned along the Earth's magnetic field lines can contribute to radar clutter at high latitudes and thus degrade radar performance. Radar clutter is concentrated at points in space where the radar is propagating perpendicular to the local magnetic field direction. Precipitating auroral electrons following magnetic field lines contribute to these electron density irregularities. The goal of this example is to use the position of the equatorward edge of the auroral electron precipitation (observed by DMSP F12 at UT=00:36 on Day 50 of 1999) and map out the magnetic field line surface defining where radar clutter might first be experienced by radar penetrating into auroral latitudes. Specifically, we will create a Kp-based statistical picture of where aurora might interfere with radar operations on Cape Cod, MA.

Start an AF-GEOSpace session and set global input parameters

- Initiate AF-GEOSpace via the Start menu (Start > Programs > AFGeospace > AFGeospace), the desktop icon, or by double-clicking on the file $AFGS_HOME\bin\AFGeospace.bat. Maximize the AF-GEOSpace user interface window. The shell windows can be minimized but must remain open for AF-GEOSpace to function.

- For this static run, set the Global Parameters as follows: *Start:Year*=1999, *Day*=50, *UT*=00:00. The Kp index and other parameters corresponding to the specified date and time may now be obtained by clicking on the *Globals: Archive* option to the right of the time input fields. The NGDC archived values of these parameters are then automatically loaded (*Kp*=5.7, *SSN*=85, *F10.7*=160.5, and *Ap*=67).

Generate and View the DMSP-F12 Orbit in 3D

- Select the *Applications* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *SATEL-APP* (satellite application). An *AppOrbit* object will be added to the *Active Modules* list and a set of Ephemeris Data options will appear in the Environment Window.

- With the *From File* Element Type option selected, click on the *File* button and a window will appears showing the contents of the folder $AFGS_HOME\models\data\EPHEMERIS. Click on the file icon labeled "dmsp.txt" and click the *Open* button. A list of DMSP satellites will appear in the *Current Element File* list in the middle of the window.

- Highlight the *DMSP F12(USA 106) 01/11/99 05:05:47.00* entry of the *Current Element File* list as it contains the orbital elements suitable for our start time. Edit the text boxes such that *Sat Name* = "DMSP F12" and *T-stop* = "02/19/99 02:00:00.0". The latter change limits the orbit to 2-hours in length. Select the *Run/Update* option in the *Edit* menu to create the orbit

data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

- Select the *Graphics* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Scroll down the *Available Modules* list and select *Earth*. An *Earth* object will be added to the *Active Modules* list and a set of Earth Options will appear in the Environment Window. Select the *Mag Dipole Grid* option and select *Display* and the Earth will appear in the default 3D window.

- Now scroll down the *Available Modules* list and highlight *Satellite*. A *Satellite* object will be added to the *Active Modules* list and a set of Satellite Options will appear in the Environment Window. Use the *Satellite* selector to choose DMSP-F12, change the *Reference Frame* selections from *Geocentric* to *Inertial (ECI)* and select *Display*, and the DMSP satellite orbit will appear with DMSP behind the Earth. Move the *Thickness* slider slightly to the right.

As mentioned in the introduction, DMSP-F12 instruments measuring precipitating particles were used to determine that there was an equatorward boundary crossing observed at UT = 00:36 on day 50 of 1999. The observed boundary was located at magnetic local time (MLT) = 20.6 hours and magnetic latitude (MLAT) = 58.5º. We will determine the statistical placement of the entire auroral equatorward edge and map the boundary out into the magnetosphere in the next section.

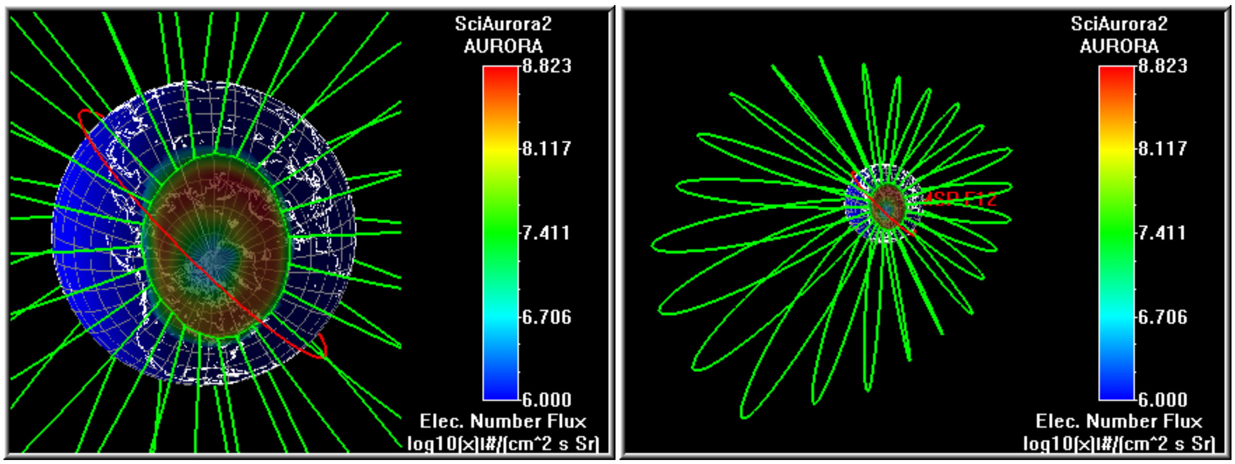
Generate and Map the Auroral Equatorward Edge Boundary

- Select the *Science* option in the *Module* menu. *Available Modules* and *Active Modules* lists will appear. Select *AURORA* from the *Available Modules* list. A *SciAurora* object will be added to the *Active Modules* list and a set of AURORA Options will appear in the Environment Window. To generate a 3D grid of Aurora data, use the *Grid Tool* option in the *Edit* menu to open the *Grid Tool* window. Edit text boxes in the *Rad, GEOC (Re)* section so that *NPoints*=7 and *Max*=2.0. Click *OK* to dismiss the window. In the Generate section of the AURORA Options, place a check next to *Eq Edge*. Select the *IGRF(1945-2010)* option in the Internal B-Field section and the *Olson-Pfitzer '77* option in the External B-Field section. In the Equatorward Edge Parameters section, select the *Use single observation* selection and two text boxes to the right will become active. Edit these text boxes such that *MLT* = 20.6 and *Observed MLAT* = 58.5. Select the *Run/Update* option in the *Edit* menu to create the auroral data set. When completed, the Model Status box will indicate that the "MODEL IS READY AND UP TO DATE."

- Select *Graphics* from the *Modules* menu. *Available Modules* and *Active Modules* lists will appear. Select *Coord Slice* from the *Available Modules* list and a *Coord Slice* object will be added to the *Active Modules* list and a set of Coord Slice options will appear. Use the *Data* button to select *Elec. Number Flux* under the *SciAurora* option and click *Display*. The model electron number flux for the current Kp value will appear. These are the electrons which can potentially contribute to radar clutter. Select the *Transparency* option and move the slider to read 0.75 to reveal the geographical features.

- To see the equatorward boundary and the mapped field lines, scroll down the *Available Modules* list and select *Field Lines* and Field Line Options will appear. Use the *Data* button

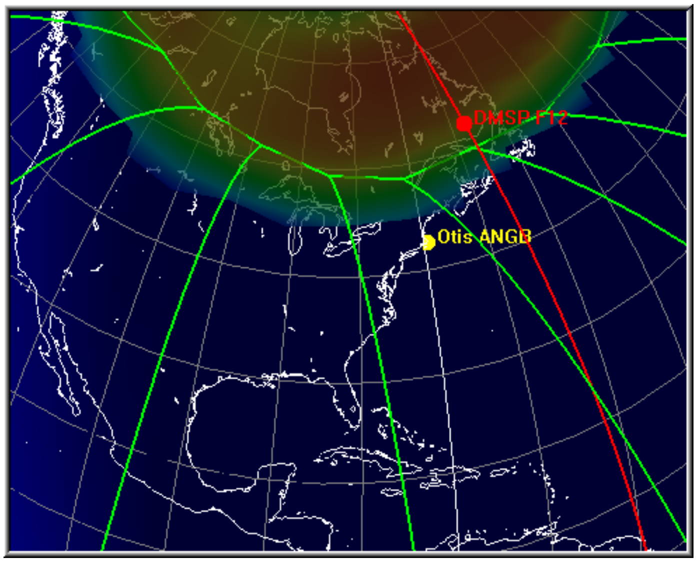
to select the *Eq. Edge* option under *SciAurora*. Increase the *Line Width* to “2” and click *Display* and a green boundary line will appear. Select *Field Lines* again from the *Available Modules* list and a second *FieldLines* entry will appear in the *Active Modules* list. This time use the *Data* button to select the *Mapped Eq. Edge* option under *SciAurora*. Increase the *Line Width* to “2” and click *Display* and magnetic field lines emanating from the boundary will appear. Highlight the *Coord Slice* entry in the *Active Modules* list (to show the color bar units) and the window should resemble the following figures. Note that at time 00:00, DMSP-F12 is in the southern hemisphere.



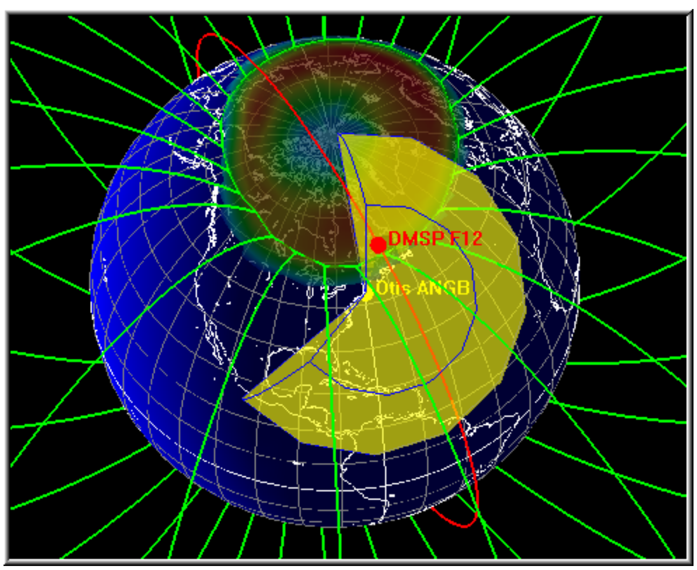
- To see where the DMSP-F12 equatorward boundary measurement was made we need to view the satellite’s location at around UT=00:36. Use the *Edit* menu to open the *Animate Tool* and edit the text boxes to match the SATEL-APP settings used earlier, i.e., set *Time Start* = “02/19/99 00:00:00.0”, *Time End* = ”02/19/99 02:00:00.0”, and *Time Step(Sec)*=”60”. Click the *Update* button and move the time slider to see that the satellite crosses the equatorward boundary line between times 00:36 and 00:37. This location (58.5 MLAT, MLT=20.6 hours) is used by the Aurora model to provide the statistical location of the equatorward auroral boundary shown at all other magnetic local times. Close the *Animate* window using the *Done* button. Use the *Viewport* menu to deactivate both the *Show Color Bar* and *Perspective* options.

Create and Display a Radar Fan Originating from Cape Code, MA

- To set up a new station for locating our radar fan, scroll down the *Available Modules* list and select *Station*. A *Station* entry will be added to the *Active Modules* list and a set of Station options will appear. Scroll down the *Stations* list and highlight the entry *Otis ANGB* (Air National Guard Base) and the properties of that station will appear in the four text boxes below. [If Otis ANGB is not already in the *Stations* list, then edit the four text boxes such that *Lat*=41.75, and *Lon*= -70.54, *Altitude(Km)*=0.0, *Label*=Otis ANGB. Click the *Add* button and there will now be an Otis ANGB entry in the *Stations* list.] Click *Display* and the station will appear out on Cape Code, MA. Use the *Color* option to change the station color to yellow by clicking on the color wheel that appears. Use the left/right mouse buttons to rotate/zoom the view to reproduce the following figure.



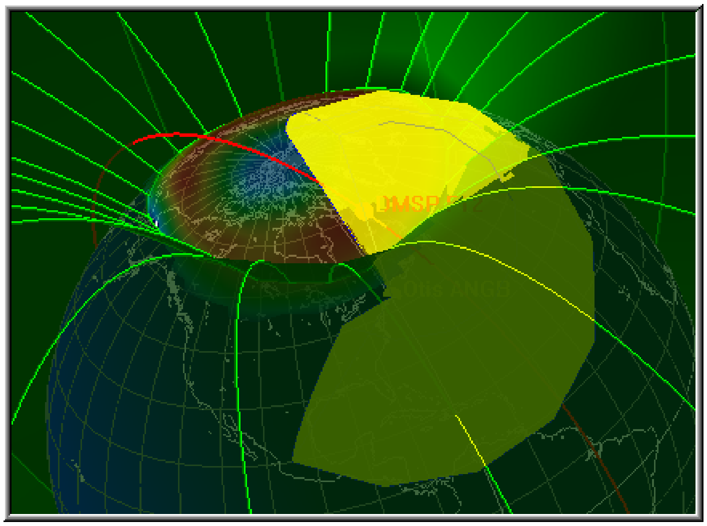
- To setup a radar fan, scroll up the *Available Modules* list and select *Emitter* and *Emitter* options will appear. Highlight the *Otis ANGB* entry in the *Origin Station* list and click *Display* and a default emitter fan will be displayed. The actual radar at Otis ANGB has a range of approximately 4000 km, azimuth limits of from -12º to +245º, and elevation angle limits of from 5º and 60º. To approximate these dimensions set the view sliders such that *View Horizontal* = 240, *View Vertical* = 55, and *View Range (Km)* = 4000. Use the *Transparency* option and set the slider to 0.30. Zoom out to achieve the following view.



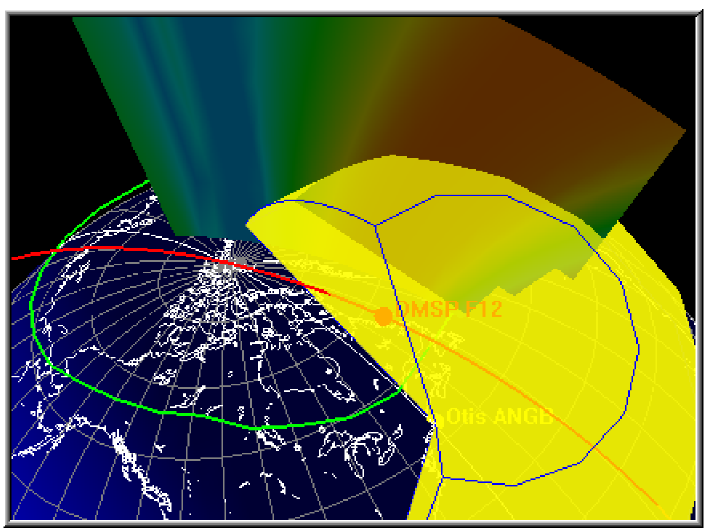
Examine the Region Where Precipitating Electrons Might Cause Radar Auroral Clutter

- Note that the radar fans penetrate poleward of the field lines mapped out along the equatorward edge boundary. It is in this region that radar auroral clutter is possible. To see where the radar actually penetrates the field lines carrying the auroral precipitation, highlight the second *FieldLines* entry in the *Active Modules* list (representing the mapped field lines). Check the Plot Type section *Filled Surface* option. Click on the *Transparency* option and

move the transparency slider that appears to a value of 0.75. Rotating the Earth up and down lets you view the region poleward of the field line surface and reproduce the next figure.



- To clean up the view for this next step, highlight the second *FieldLines* entry in the *Active Modules* list and uncheck *Display*. To view the intersection of precipitating particles and the radar fan is to highlight the *Coord Slice* entry in the *Active Modules* list and select Cut Plane*: C2*. This action creates a coordinate slice along constant longitude meridians. Move the *Position Value* slider between the values 0.3 and 0.425 to see where the particle flux and fan overlap and obtain the view in the next figure. Radar clutter requires propagation perpendicular to the local magnetic field direction and the presence of precipitating electrons so the affected volume is actually much smaller than the one defined using these visualization tools.



This completes the Example of Radar Auroral Clutter.

PRODUCT INFORMATION

AF-GEOSpace was developed by the Space Vehicles Directorate of the Air Force Research Laboratory. Duplication or redistribution of AF-GEOSpace is prohibited.

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To report program bugs, get technical help, or obtain a copy of AF-GEOSpace, please contact *Robert.Hilmer@us.af.mil*. Comments on AF-GEOSpace's capabilities and suggestions for future versions are appreciated.

ERRATA

While the AF-GEOSpace Version 2.5.1 software has been extensively tested, there remain known software bugs. In most cases, each bug listed is labeled using the most relevant entry in the Table of Contents.

AURORA Science Module: 3-D extensions (using *Edit* Menu *Grid Tool* option) to get Gridded Data at radii greater than 10 Re do not function when selecting the Tsyganenko ’87 or ’89 external B-Field models.

COLOR MAP Graphical Option: Curve option not functional.

CUTOFF Science Module: Locks up if Cartesian Grid Tool is used with point (0, 0, 0).

DATA MAP Graphical Option: Log10 not functioning properly when applied to the PARAMESH related graphical objects.

Edit Menu-Data Tool: During the animation of dynamic run results, the selected *Data* field label will vanish but the displayed *Data Viewer* window values remain valid.

EMITTERS Graphics Module: Tracking feature is not functional.

Global Inputs Graphics Module: Values do not plot properly in 1D across year boundary.

GRID Data Module: “Selected Data Parameters Have Changed: ‘Run/Update’ to Load” messages does not update until user leaves and then returns to the active GRID Data module.

ISPM Science Module: Software may lockup if input formats are not followed, e.g., inserting “2.0” instead of “B2.0” as a *Backg. Class* input or inserting a *Flare Lat (deg N)* > 90 degrees. For hints on possible input format problems, check the file called “dbg.txt” in the ISPM folder generated in the scratch folder at run time.

MSM Science Module: Does not work across year boundary or for first day of a year.

Model Status Text Box: For dynamic runs with large number of steps (>25), format of text written to Model Status box can become disrupted, i.e., multiple entries written to a single line.

ORBIT PROBE Graphics Module: Output does not animate properly across year boundaries.

PARAMESH: If in *Static* mode (no Stop time specified at top of Environment Window), the *Edit: Animate* slider must be moved manually because the animate button only works in *Dynamic* mode.

PARAMESH-COORDSLICE: Cut Plane *C1* not working for spherical coordinates.

PARAMESH-FIELDLINES II: For *Current Group* creation, option *Last Position* not working properly and *Sphere* not implemented.

PPS Science Module: Expert mode locks if selecting Differential energy spectra and entering Spectral Slope equal 1.00. *Plot Options* popup window *Auto* buttons no functioning properly.

RAYTRACE Application Module: *File* menu *Open Model* option not working when Jones-Stephenson 3D tracer is used or when in *Dynamic* mode. Solution is to save PIM Science Module results, record ray tracing GUI settings, and rerun tracer application.

SATELLITE Graphics Module: Satellite orbits do not animate properly in 3D across year boundaries.

STOA Science Module: *File* menu *Save Model* option only saves module settings. To recreate results use the *Save Model* and *Open Model* options, then use the *Edit* menu *Run/Update* option to rerun the module.

VOLUME Graphics Module: Does not work for data rendered in cylindrical coordinates.

WBPROD Application Module: Text window for the *All* selection only shows results for the first satellite processed from the list. Model Save/Open not working. The numbers from the "Fade" column of the *Text: All* option text display should also appear as the second column of the *Text: Summary* text display, so suggest running only one satellite at a time.

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